



L'identificazione dei parametri idraulici nel modello geotecnico

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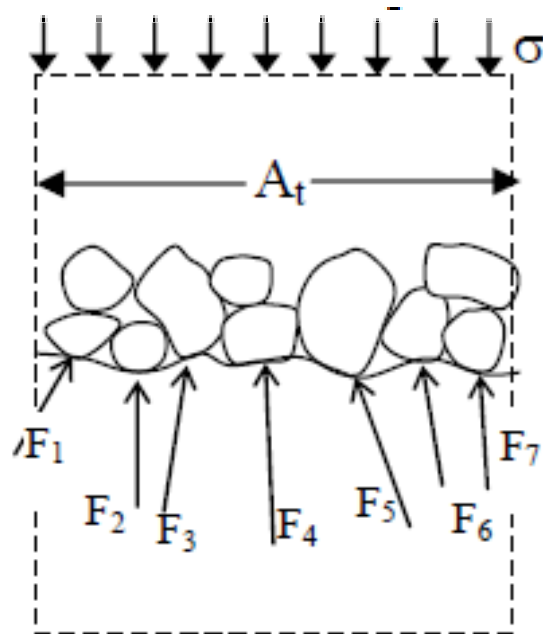
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IL PRINCIPIO DELLE TENSIONI EFFICACI

Le esatte parole con cui Terzaghi enuncia il principio delle tensioni efficaci alla 1^a Conferenza Internazionale di Meccanica delle Terre (Londra, 1936) sono le seguenti:

$$\sigma = \sigma' + u$$



“The stress in any point of a section through a mass of soil can be computed from the total principal stresses σ_1 , σ_2 and σ_3 which act at this point. If the voids of the soil are filled with water under a stress u the total principal stresses consist of two parts. One part u acts in the water and in the solid in every direction with equal intensity. It is called the neutral stress (or the pore pressure).

The balance $\sigma_1' = \sigma_1 - u$, $\sigma_2' = \sigma_2 - u$, and $\sigma_3' = \sigma_3 - u$ represents an excess over the neutral stress u and it has its seat exclusively in the solid phase of the soil. This fraction of the total principal stress will be called the effective principal stress”.



INFLUENZA DEI FLUIDI NEI PROBLEMI GEOTECNICI

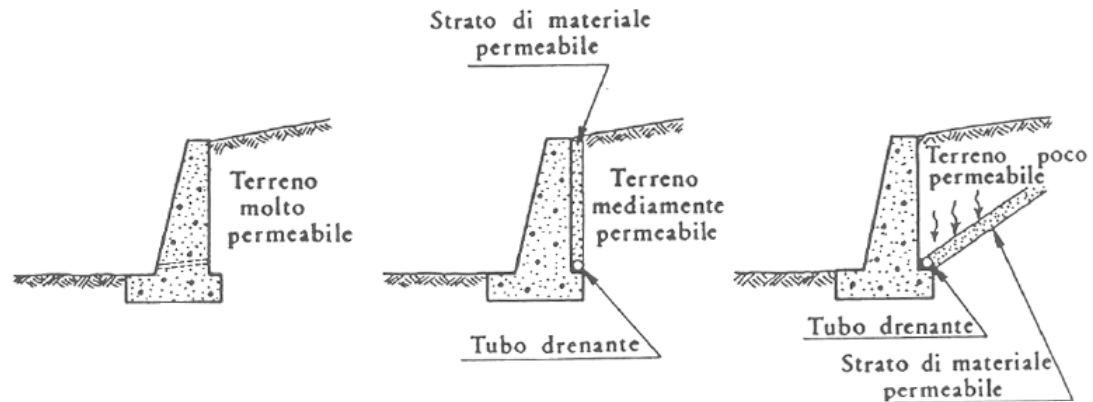


Fig. 12.5 - Tipi di drenaggio a tergo di muri a gravità

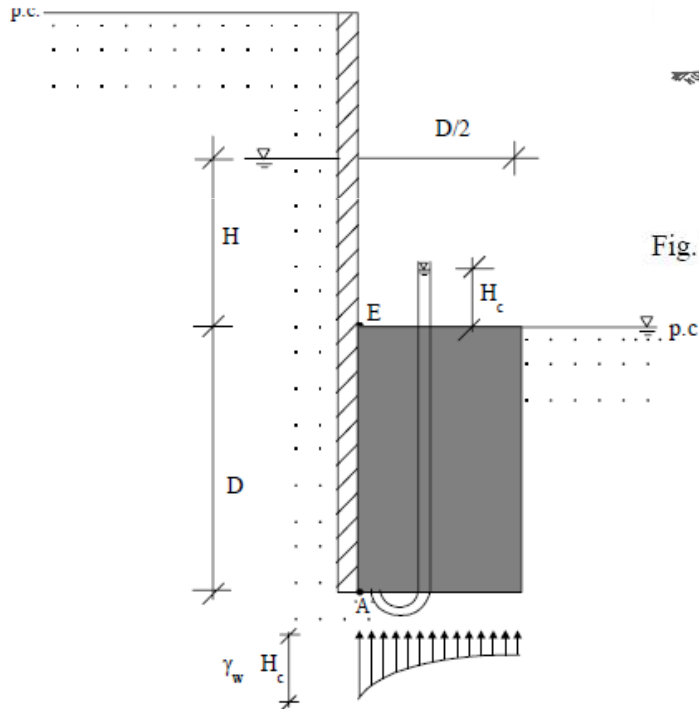


Figura 4.21 – Distribuzione delle sovrappressioni al piede di un diaframma in un mezzo di spessore infinito

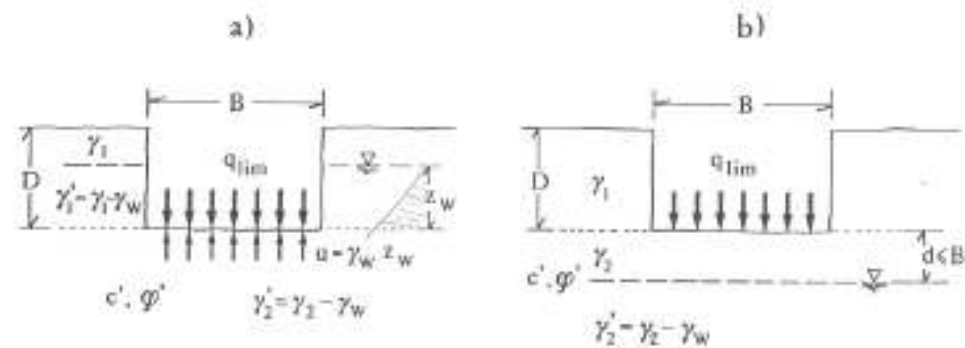


Fig. 10.7 - Schemi per valutare l'influenza della falda idrica sul carico limite in termini di tensioni efficaci



MECCANISMI DI DEFORMAZIONE

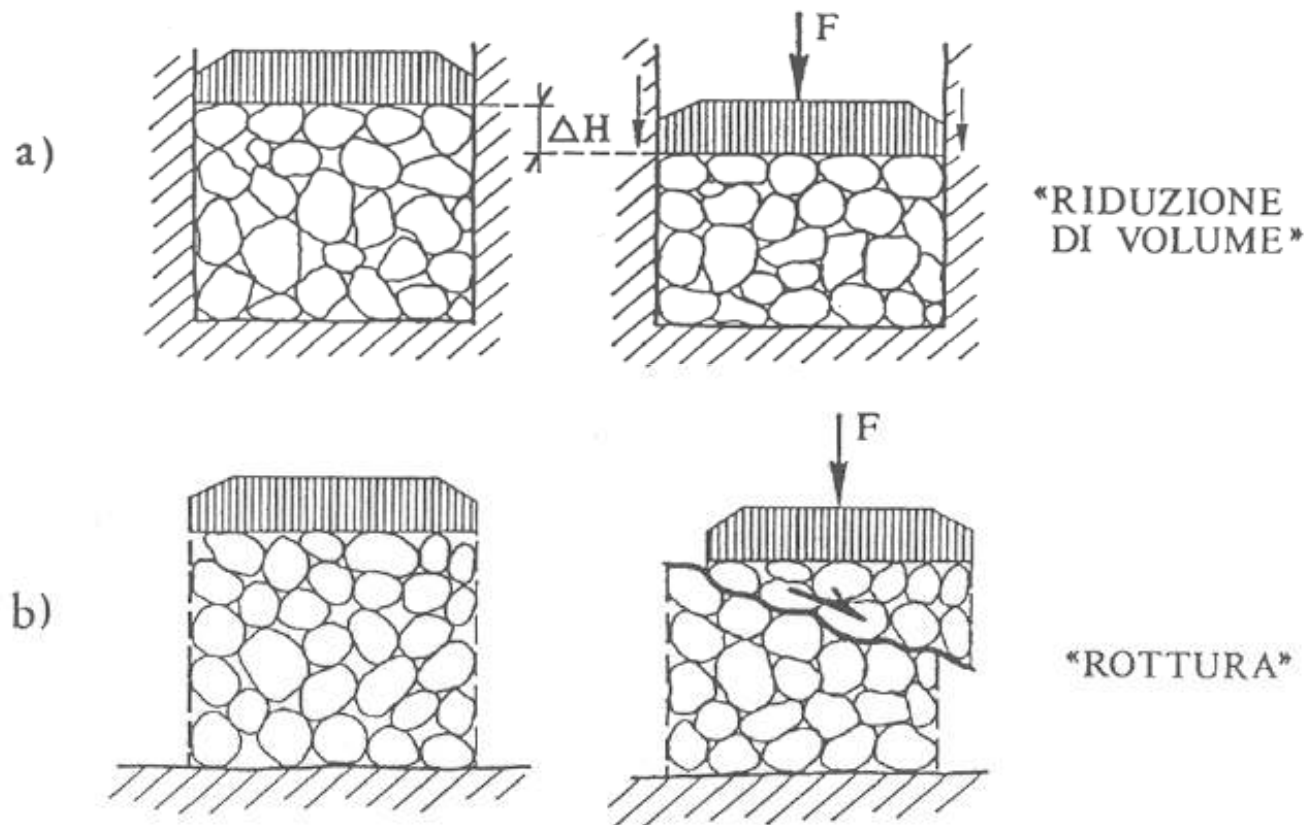


Fig. 7.2 Condizioni di deformazione di un elemento di terreno: a) deformazioni laterali impedito; b) deformazioni laterali parzialmente impedito



ROTTURE ARGINALI



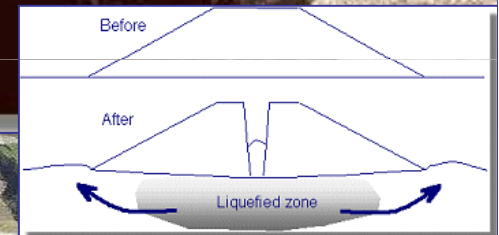


STABILITA' DEI VERSANTI





LIQUEFAZIONE DELLE SABBIE

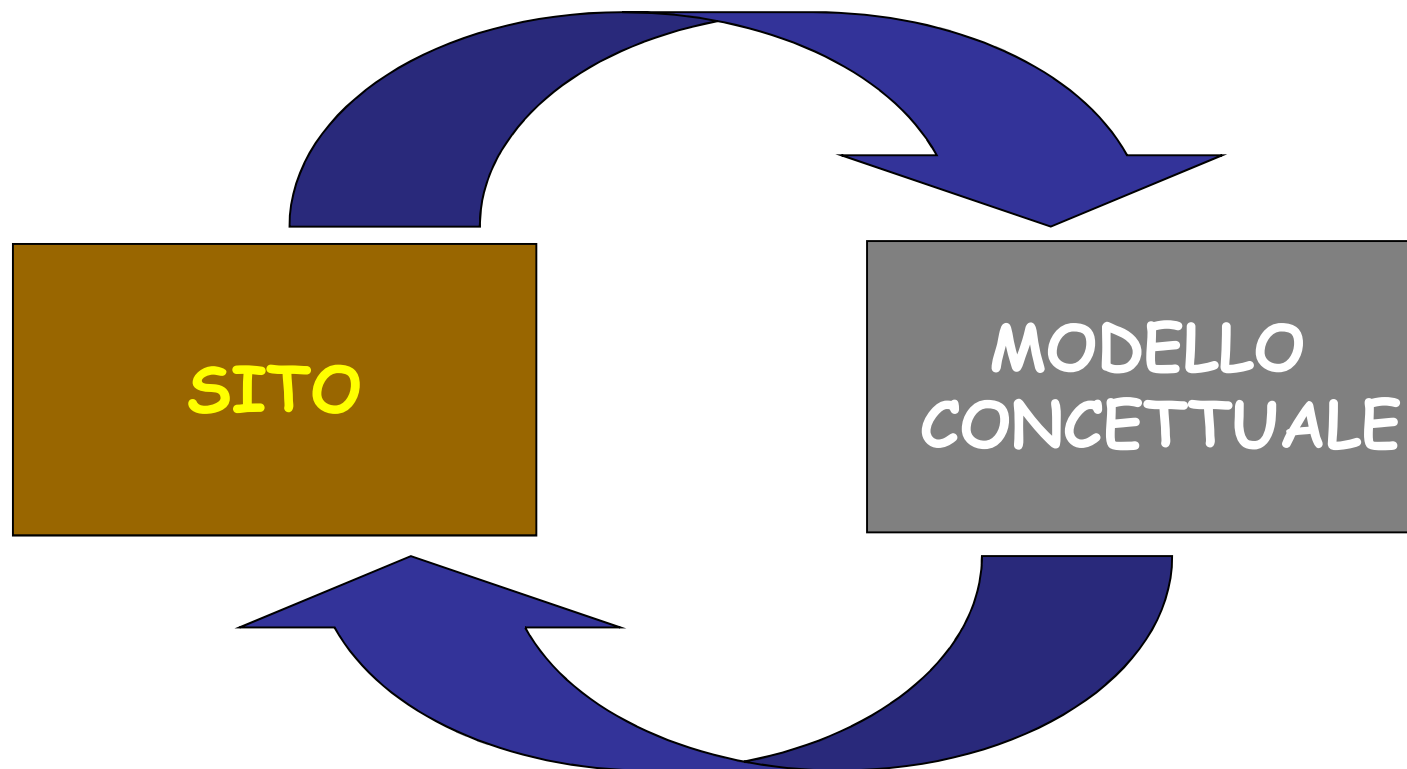




UN MODELLO CONCETTUALE



CARATTERIZZAZIONE DEL SITO



PROGETTAZIONE DELLA CARATTERIZZAZIONE



Tematiche idrologiche

Alluvioni

Instabilità dei versanti montani

Contaminazione dei suoli e delle acque

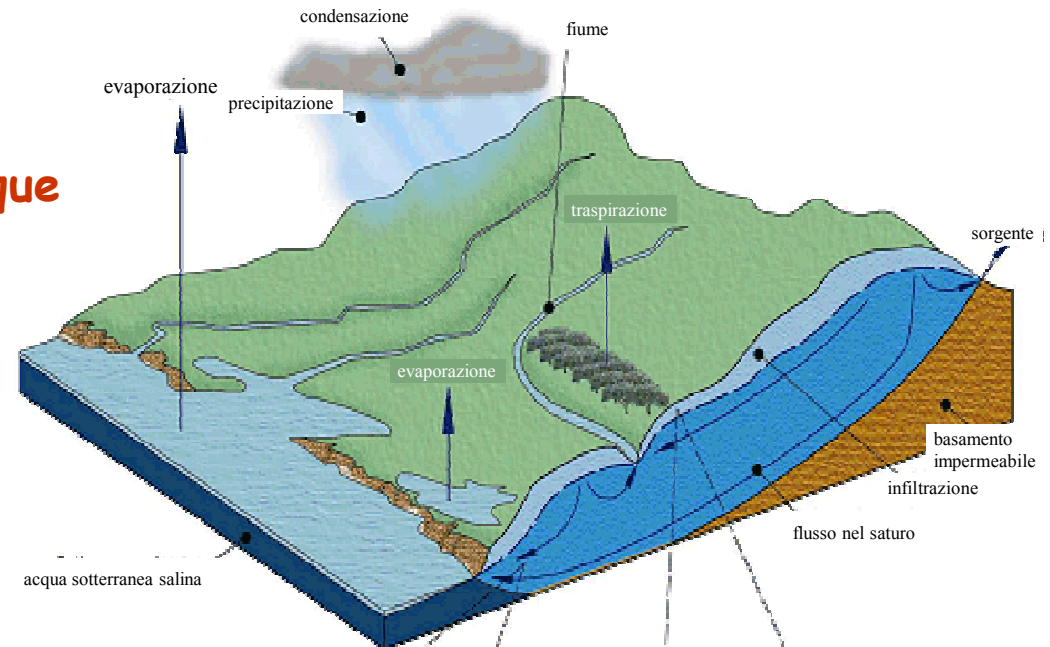
Impatto sul clima

L'acqua nel sottosuolo

trasporta energia

modifica lo stato di stress

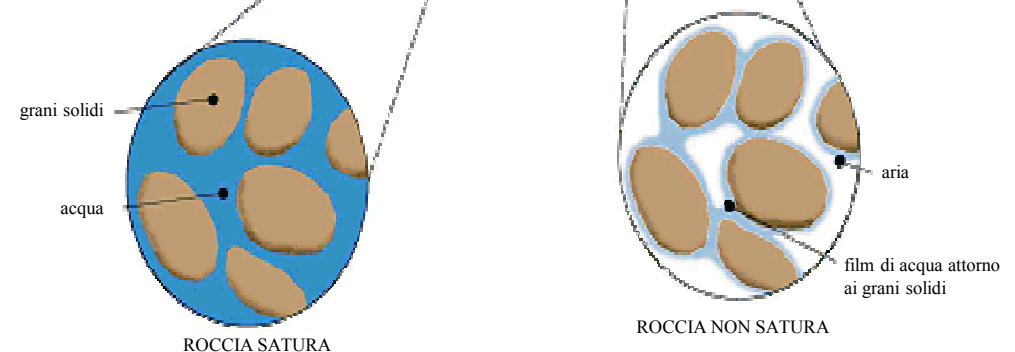
trasporta contaminanti



Idrologia
(fluido-dinamica ambientale)



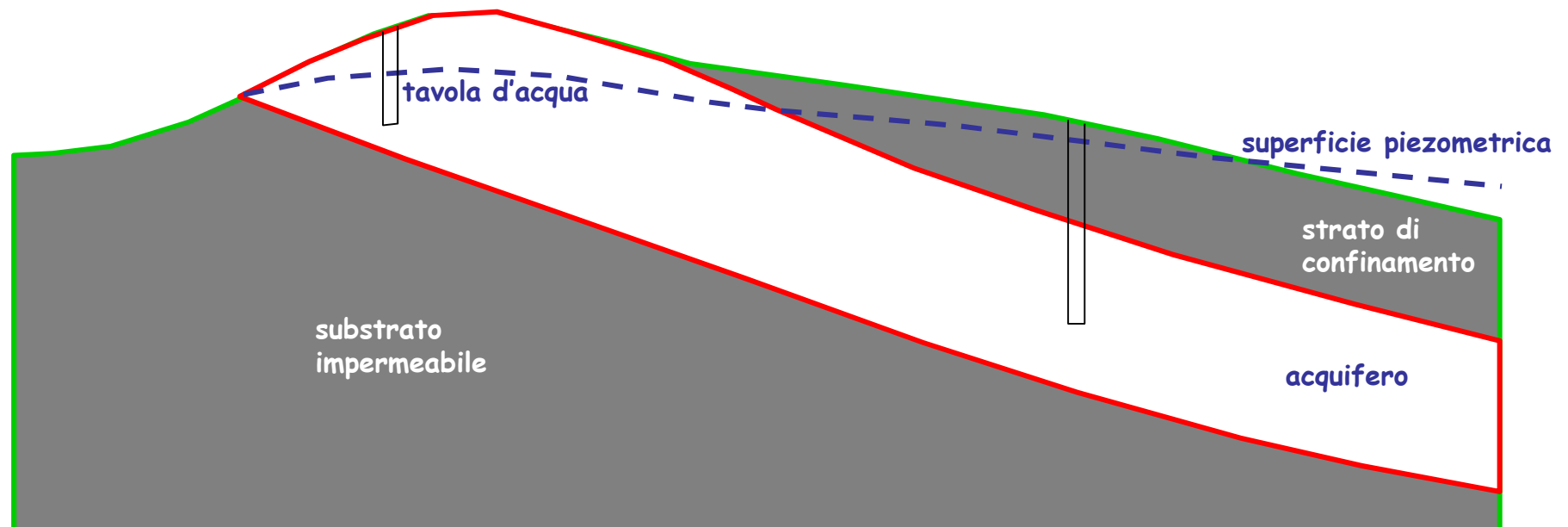
Geofisica
(idro-geofisica)





Aspetti del problema geotecnico:

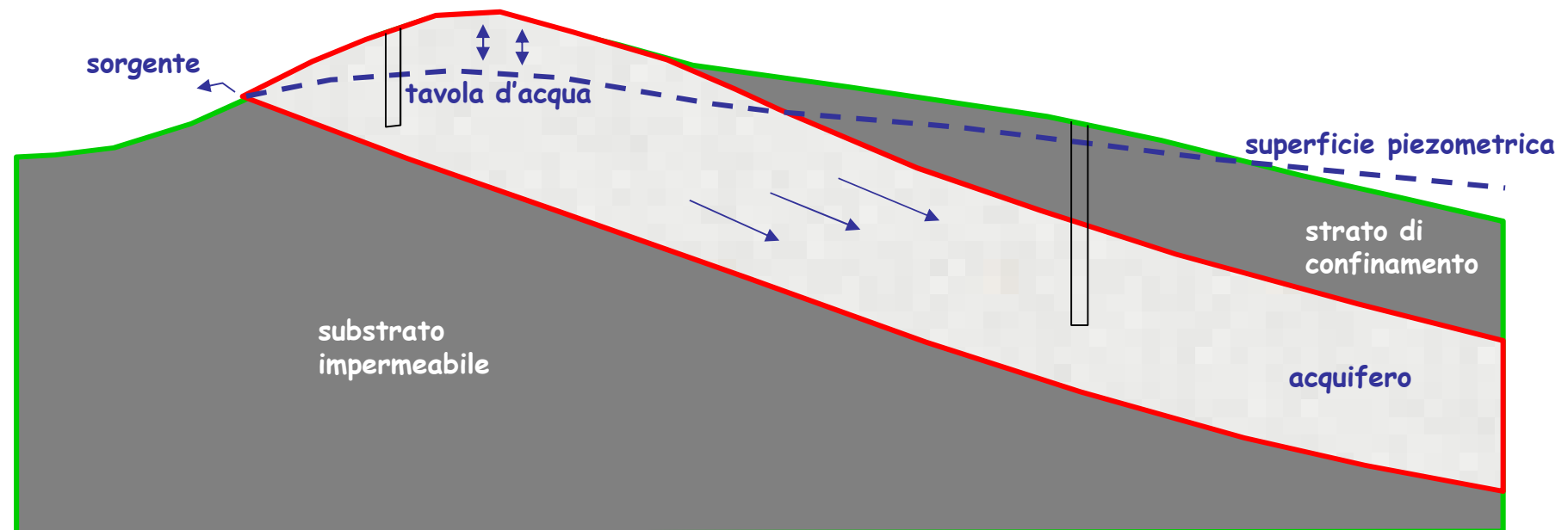
- struttura





Aspetti del problema geotecnico:

- struttura
- dinamica dei fluidi

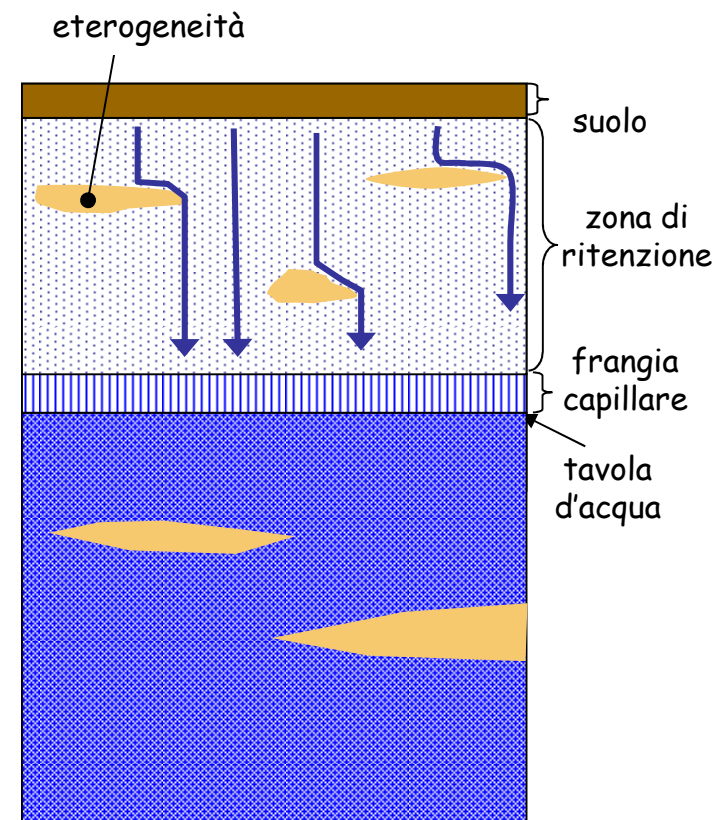




La zona non satura (vadosa)

Migrazione dell'acqua ~ verticale

- ❑ trasporto e rimozione dei contaminanti
- ❑ interfaccia con l'atmosfera
- ❑ meccanica dei suoli e forze capillari
- ❑ inondazioni e contenuto idrico dei suoli



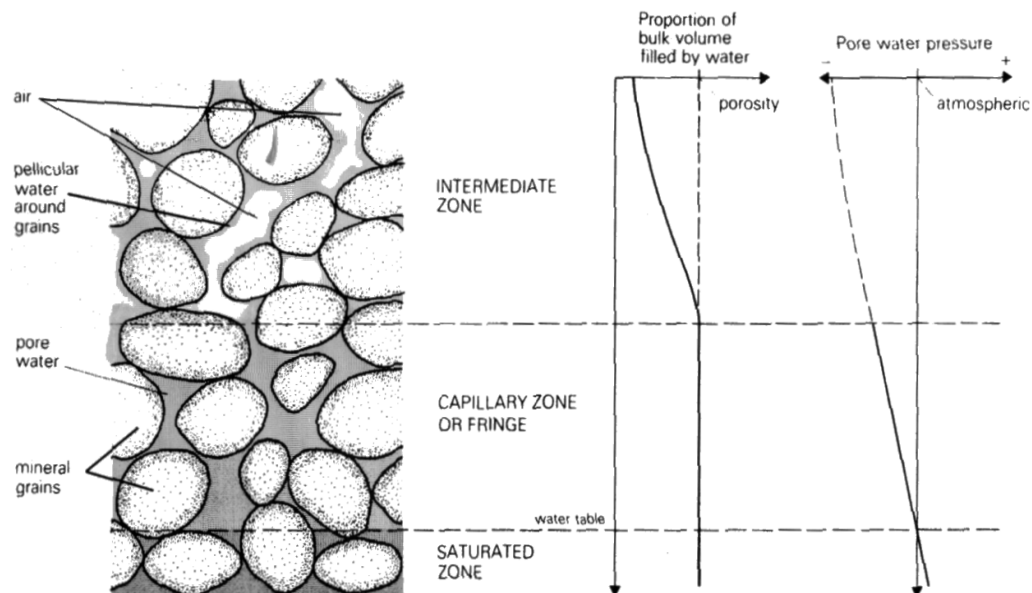
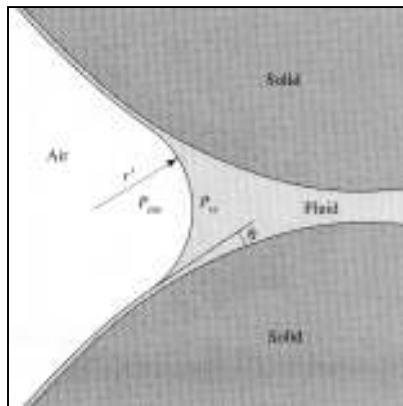


Il non saturo

Sotto la tavola d'acqua, i pori sono saturi al 100%, con pressione che aumenta con la profondità. La **tavola d'acqua** si può definire come la superficie dove la pressione è atmosferica.

Sopra la tavola d'acqua c'è una zona in cui i pori sono ancora saturi ma la pressione è minore di quella atmosferica (**frangia capillare**)

Ancora più in alto, la **saturazione è inferiore al 100%**, e la pressione diminuisce ancora, raggiungendo valori fortemente negativi.

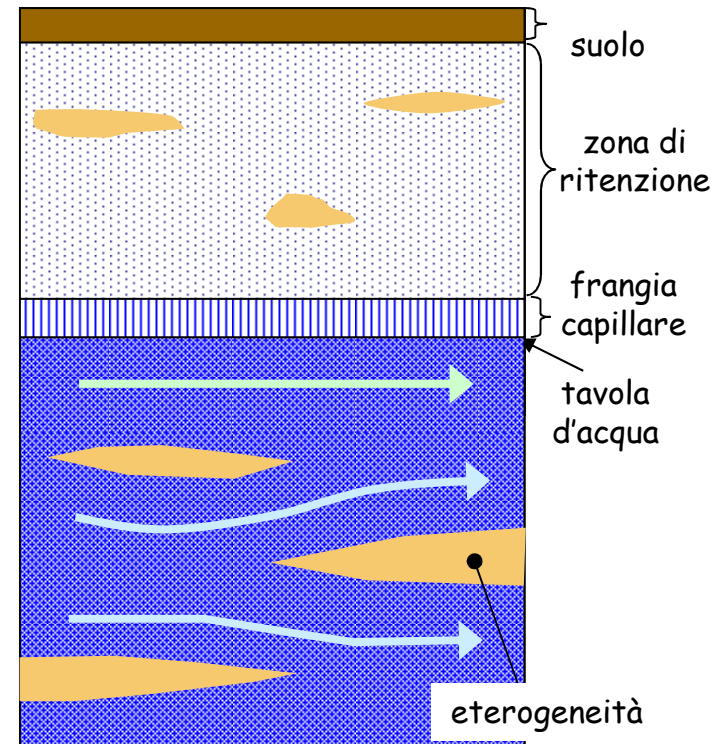




Il saturo

Migrazione dell'acqua ~ orizzontale
controlla:

- ❑ flusso di base dei corsi d'acqua
- ❑ cambiamenti nello stato di stress
- ❑ trasporto di contaminanti
- ❑ risorse idriche



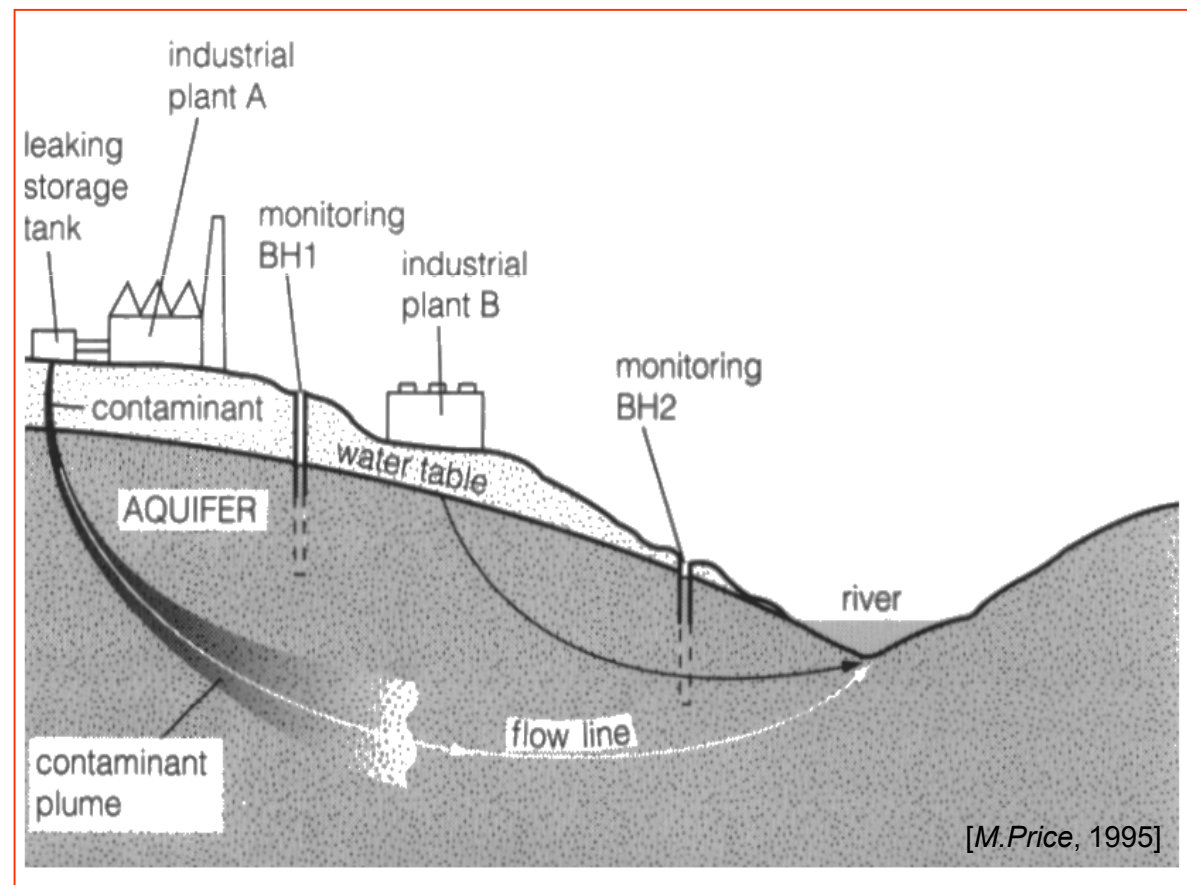
Il saturo

Il moto di contaminanti in fase disciolta è chiaramente **controllato** in prima istanza **dal moto dell'acqua** stessa.

La **convezione** è il moto del soluto secondo le linee principali di flusso delle acque sotterranee.

La **dispersione meccanica** causa la diluizione del soluto nell'acquifero.

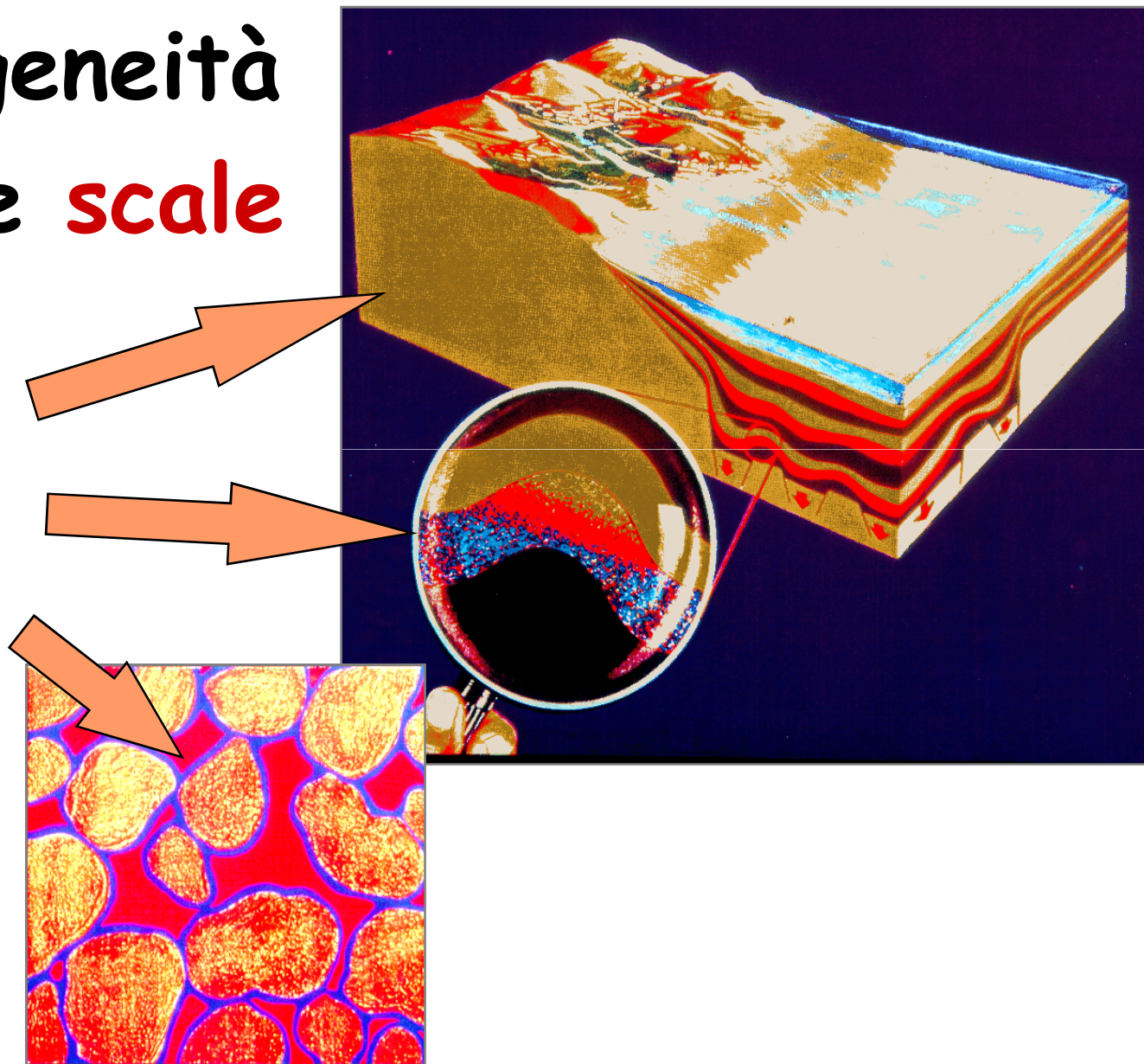
Entrambi i meccanismi sono dovuti al moto idrico, considerato dall'osservatore a scale fisiche diverse.





Eterogeneità a varie scale

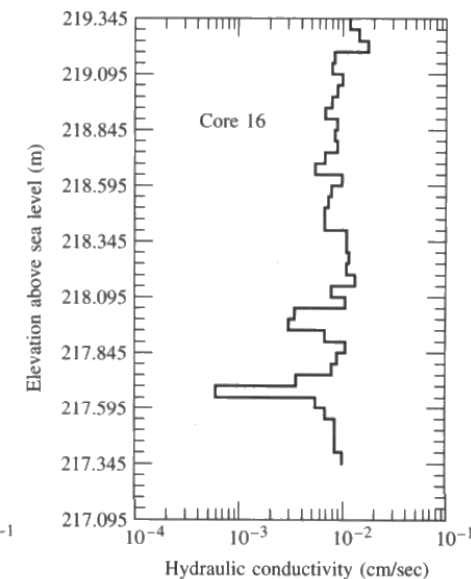
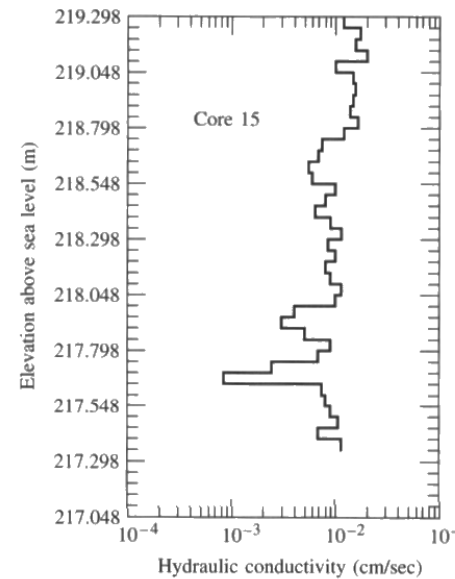
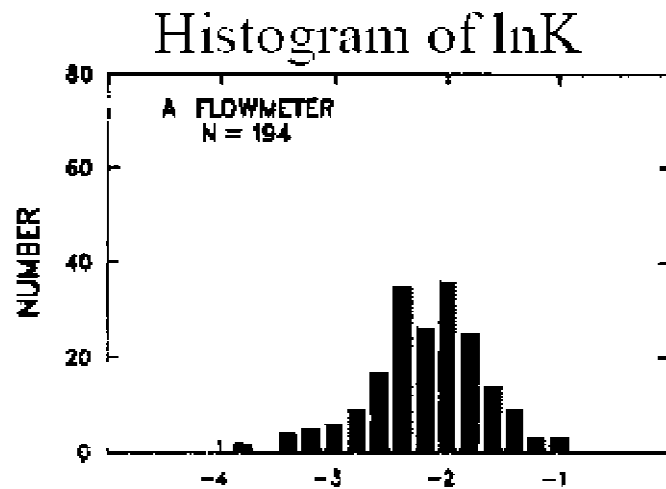
- mega
- macro
- micro



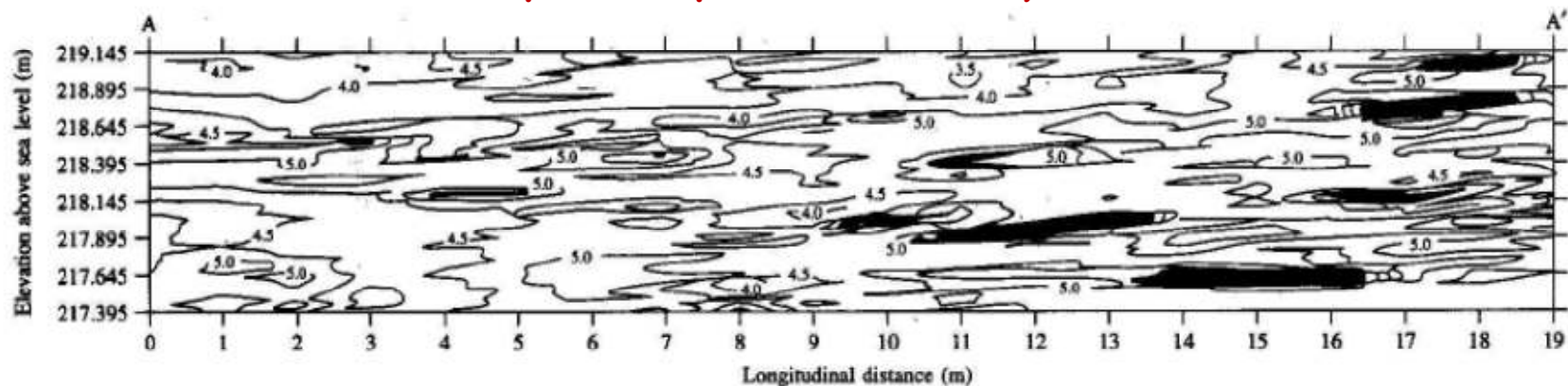


Eterogeneità alla macro scala: conduttività idraulica

Le variazioni spaziali della velocità di flusso e quindi la macro-dispersività dipendono dalla variabilità nello spazio della conducibilità idraulica K



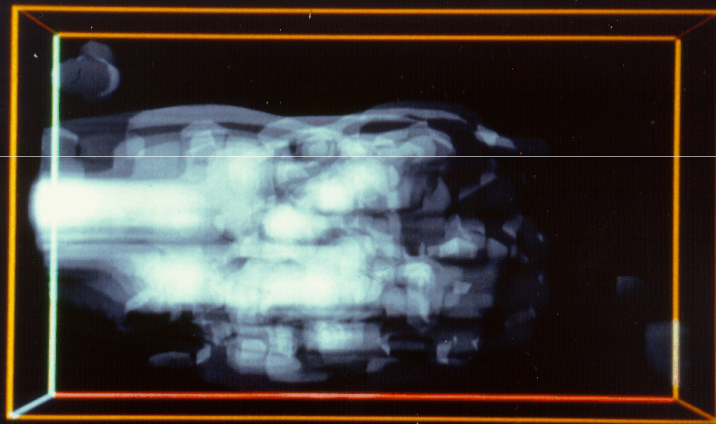
The Borden aquifer experiment [Sudicky et al., 1986]



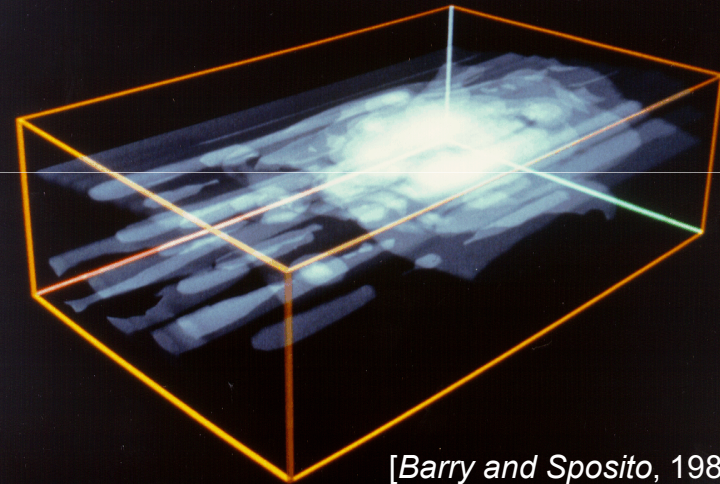
Il saturo

Dall'analisi dei momenti spaziali dei plume di soluti è possibile ricavare la macro-dispersività, e da questa le statistiche del campo di K

(Vista dall'alto)



Borden experiment: plume di bromuro

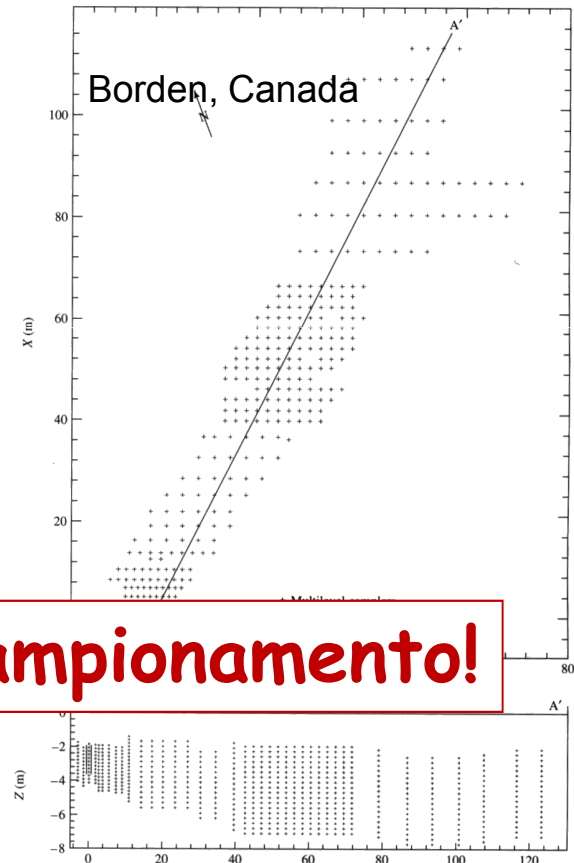


[Barry and Sposito, 1988]

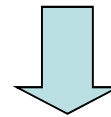
Il saturo

Per effettuare un'analisi attendibile dei momenti spaziali dei plume di soluti è necessario un campionamento molto fitto nel tempo e nello spazio.

[Mackay et al., 1986]



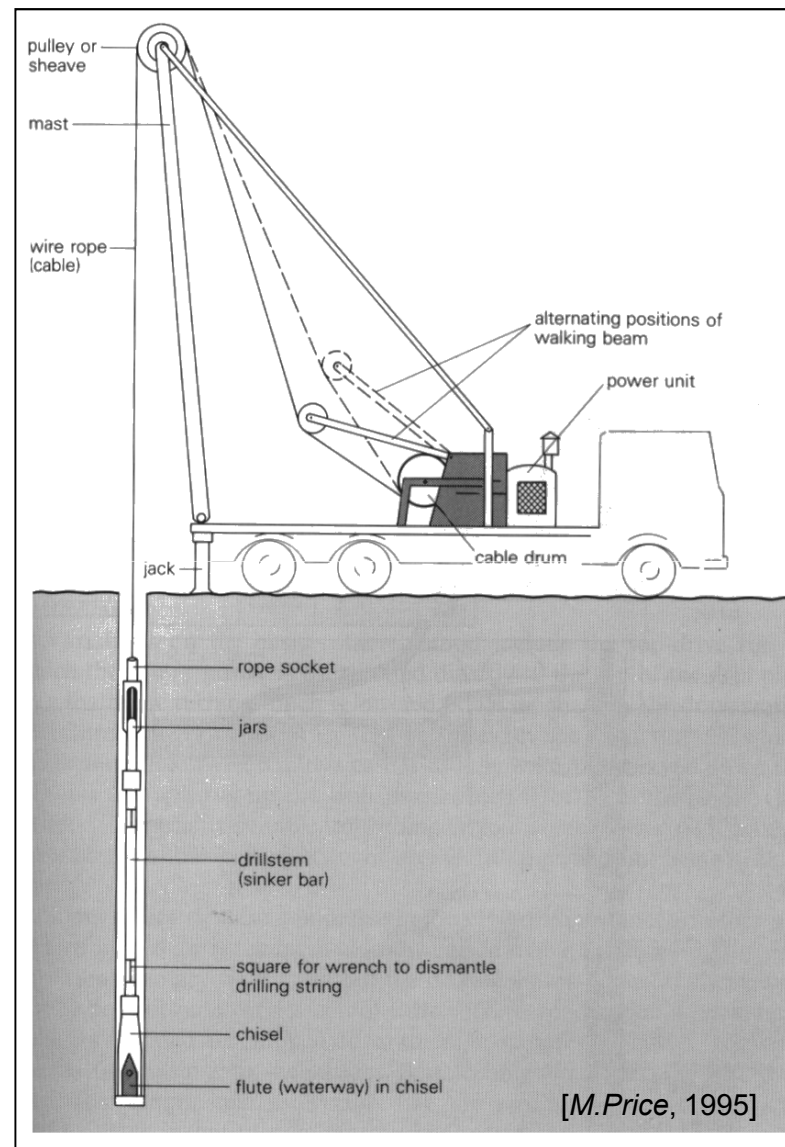
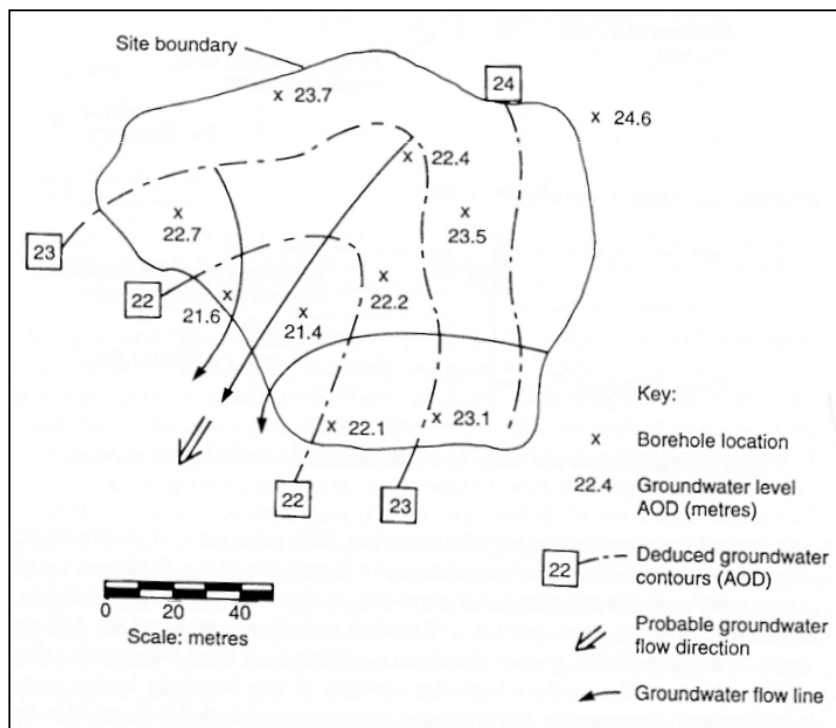
Enorme numero di punti di campionamento!



Tecnica non applicabile nella pratica comune



INVESTIGAZIONE DIRETTA DEL SOTTOSUOLO



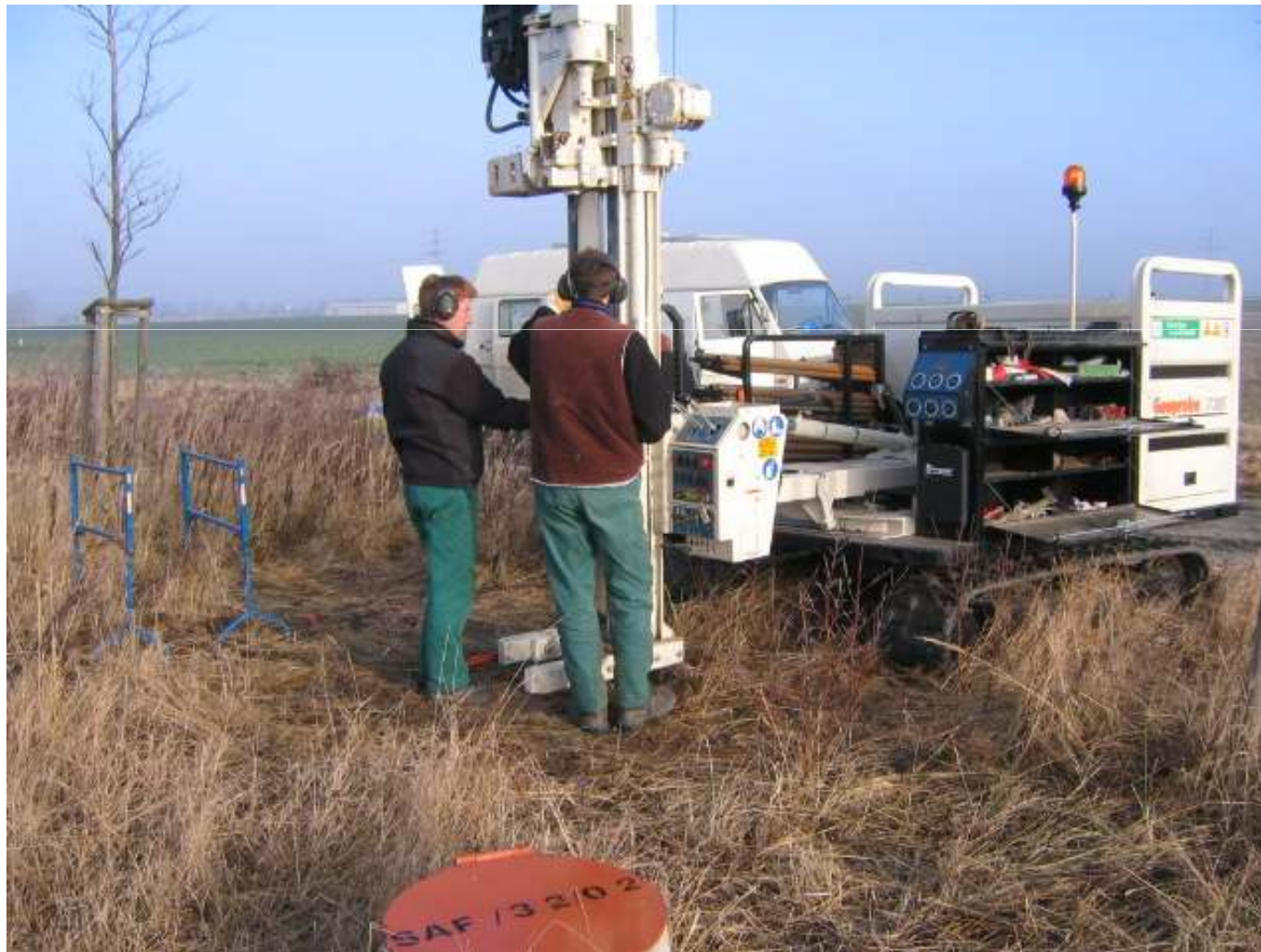


La caratterizzazione con tecniche di perforazione tradizionali è lenta e costosa





... ma può essere effettuata in modo molto più
efficiente con tecniche di Direct Push





Perforazione estremamente rapida
anche con diametri non trascurabili (2")

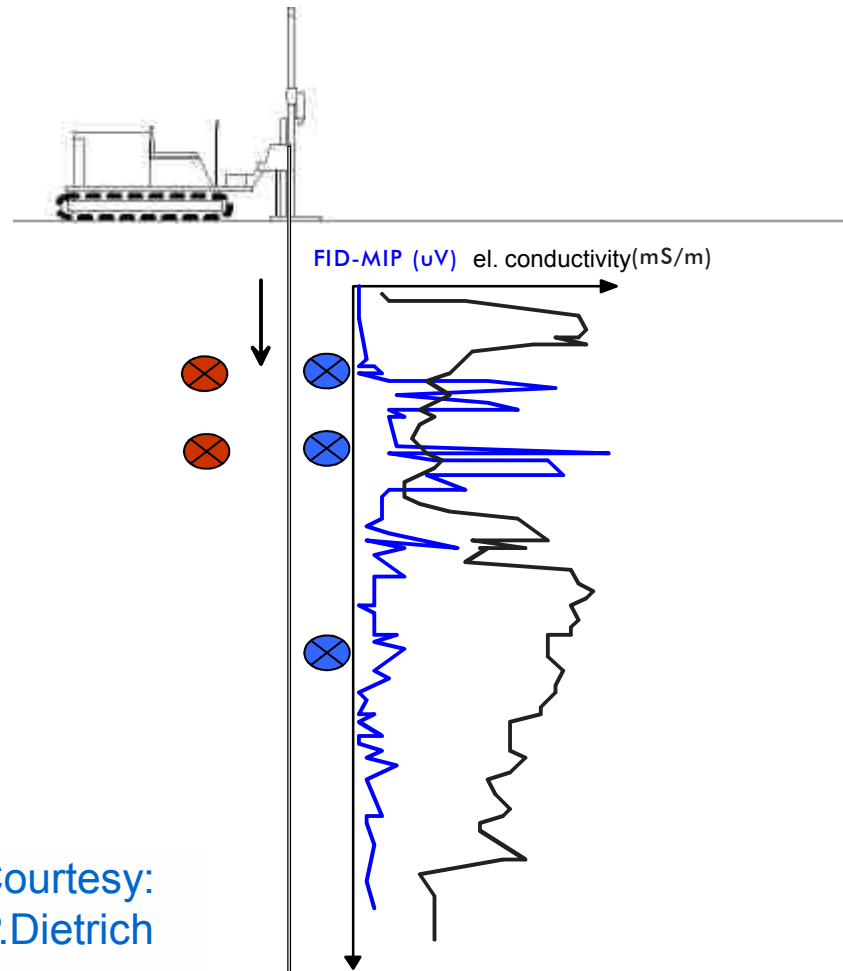
Tecnologia
"Direct Push"


Courtesy:
P.Dietrich

 HELMHOLTZ
CENTRE FOR
ENVIRONMENTAL
RESEARCH - UFZ

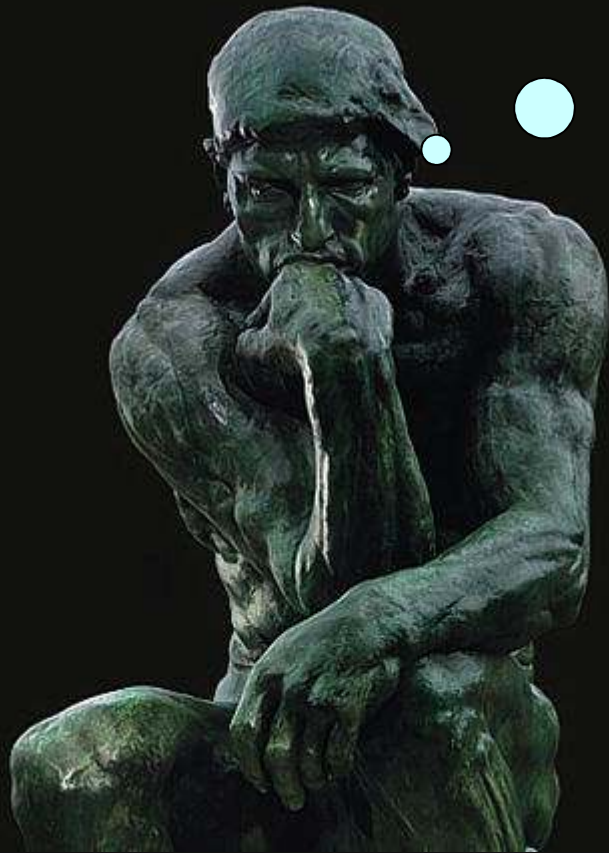


Usi della tecnologia "Direct Push"



- **misure di proprietà fisiche**
 - conduttività elettrica
 - conduttività idraulica
 - indici di contaminazione
 - ...
- **campionamento** 
 - di acque sotterranee
 - di suoli
 - di gas interstiziali
- **installazione** 
 - punti di campionamento
 - dosimetri
 - sensori
 - elettrodi
 - microcosmi batterici

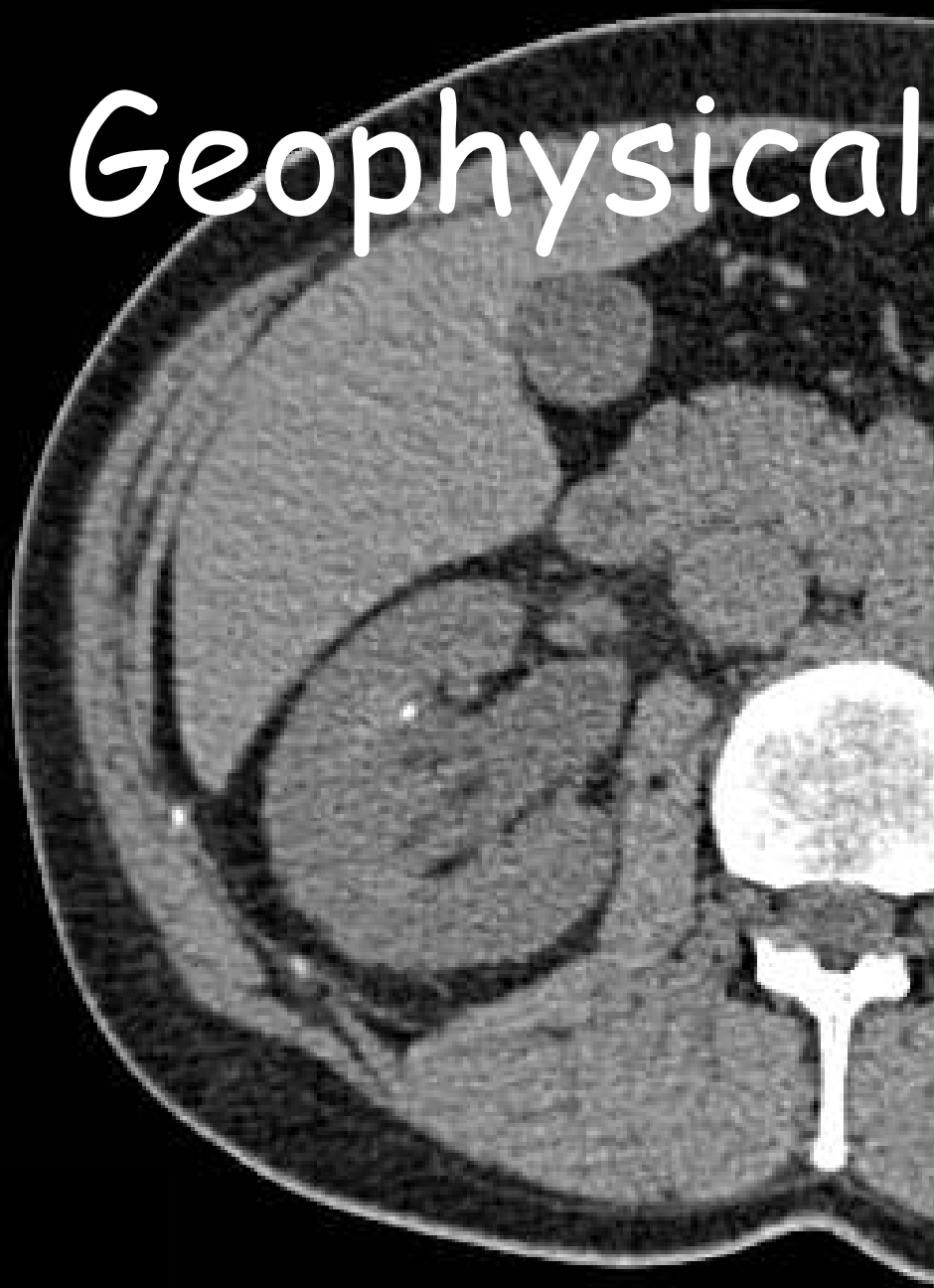
Courtesy:
P.Dietrich



Tutte queste
tecniche sono
adeguate?
sufficienti?



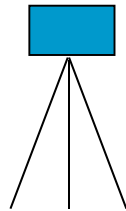
Geophysical Imaging





La misura geofisica

strumento



G = quantità geofisica misurata

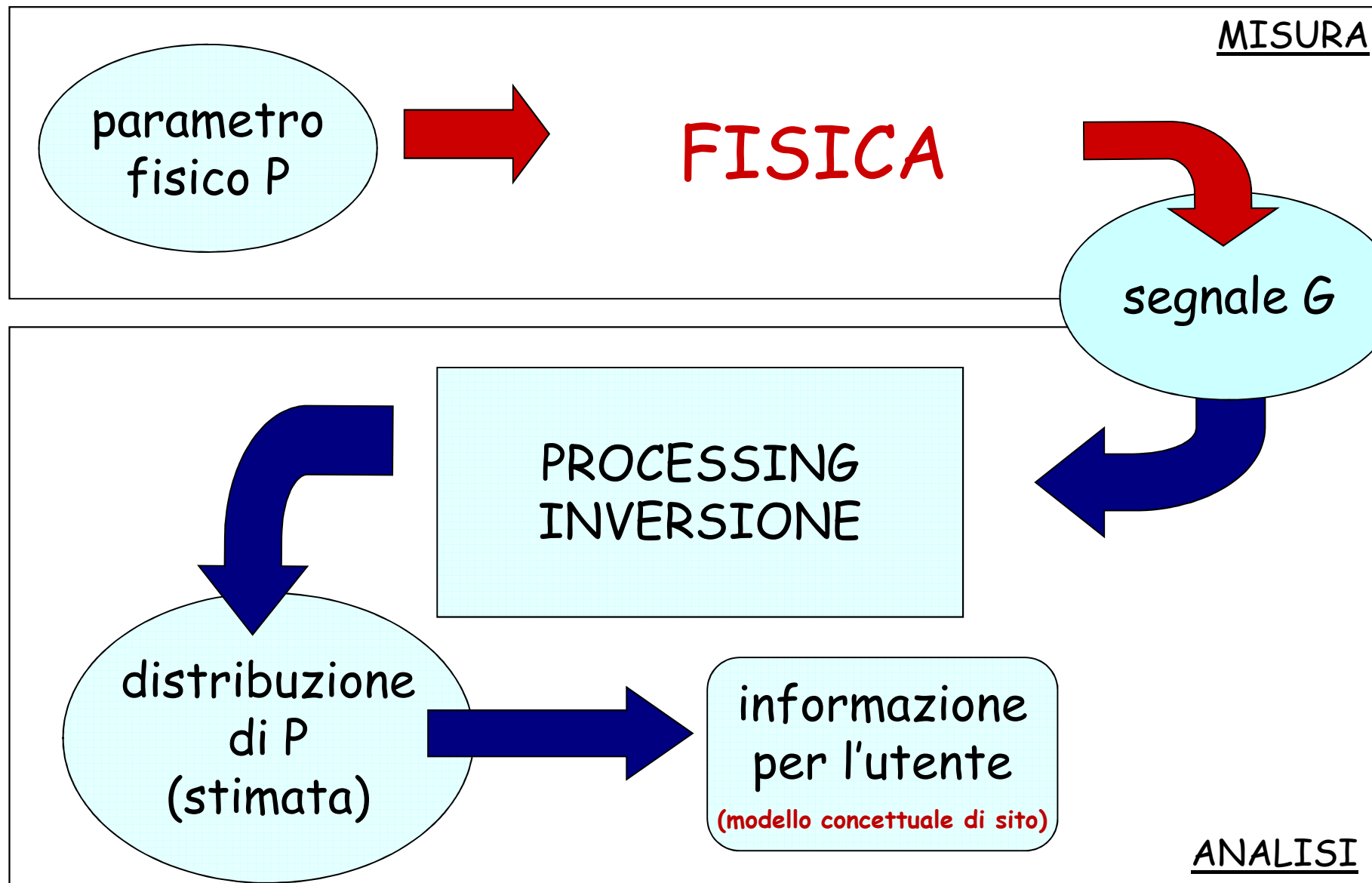
P = parametro geofisico del sottosuolo che condiziona G

dominio di investigazione

$$G = G(P, F = \text{condizioni forzanti})$$



MISURA ED ANALISI IN GEOFISICA APPLICATA





METODI GEOFISICI

- Geoelettrica
- Sismica
- Georadar
- Metodi EM
- Gravimetria
- Magnetismo
- ...



?

APPLICAZIONI

- Esplorazione per idrocarburi
- Esplorazioni per minerali
- Studi ingegneristici
- Studi idrogeologici
- Identificazione di contaminanti
- Studi geologici regionale
- Applicazioni forensi
- Studi archeologici
- ...



**METODI
GEOFISICI**



APPLICAZIONI

La scelta viene fatta in base dei seguenti criteri:

- l'obiettivo dell'applicazione deve essere compatibile con la **grandezza fisica** misurata
- Il metodo deve aver sufficiente **risoluzione** spaziale (e temporale) e sufficiente **penetrazione**
- costo
- logistica
- impatto ambientale



Applicable methods and measured physical quantities

METHOD	PHYSICAL PROPERTY
Seismics	elastic properties and density
Electro-magnetic methods	electrical conductivity /resistivity
DC resistivity methods	electrical conductivity /resistivity
Gamma ray spectrometry	natural gamma radiation
Ground Penetrating Radar	dielectric constant (electrical conductivity)
Magnetics	magnetic susceptibility / permanent magnetization
Gravimetry	density
(Spectral) Induced Polarization	complex electrical conductivity
Self Potential	DC sources
Nuclear Magnetic Resonance	free water content and decay time



Applicable methods and subsurface characteristics

METHOD	STRUCTURE	DYNAMICS
Seismics	++	
Electro-magnetic methods	+	++
DC resistivity methods	++	++
Gamma ray spectrometry	++	
Ground Penetrating Radar	++	++
Magnetics	+	
Gravimetry	+	++
(Spectral) Induced Polarization	+	+
Self Potential		++
Nuclear Magnetic Resonance	+	++



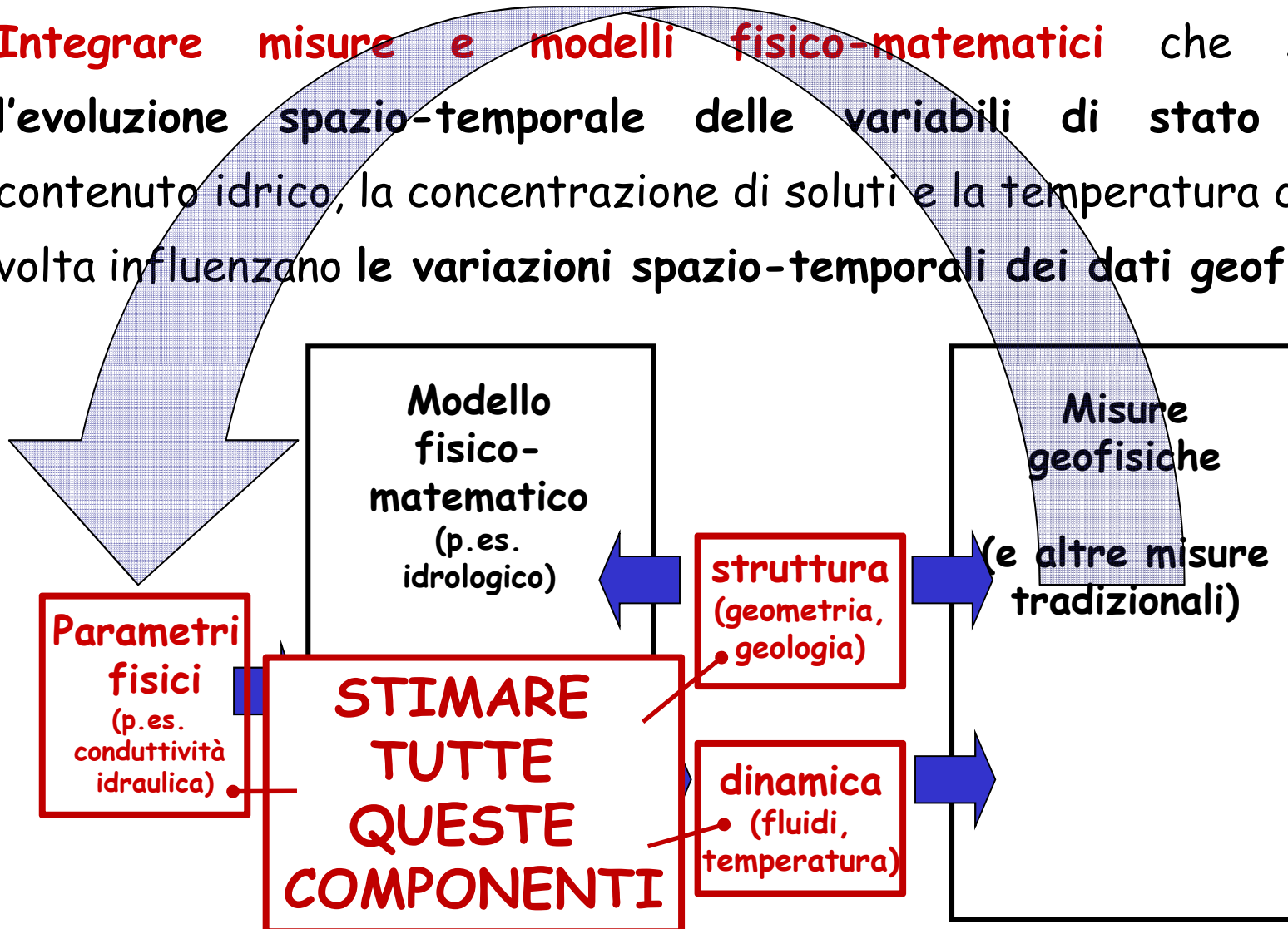
Applicable methods and subsurface characteristics

METHOD	STRUCTURE	DYNAMICS
Seismics	++	
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DC resistivity methods	++	++
Gamma ray spectrometry	++	
Ground Penetrating Radar	++	++
Magnetics	+	
Gravimetry	+	++
(Spectral) Induced Polarization	+	+
Self Potential		++
Nuclear Magnetic Resonance	+	++



INTEGRAZIONE CON I MODELLI PREDITTIVI

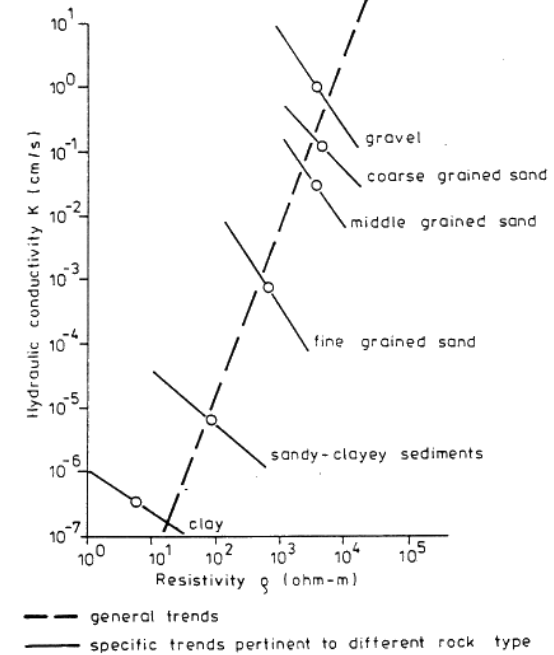
Integrare misure e modelli fisico-matematici che spieghino l'evoluzione spazio-temporale delle variabili di stato quali il contenuto idrico, la concentrazione di soluti e la temperatura che a loro volta influenzano le variazioni spazio-temporali dei dati geofisici.



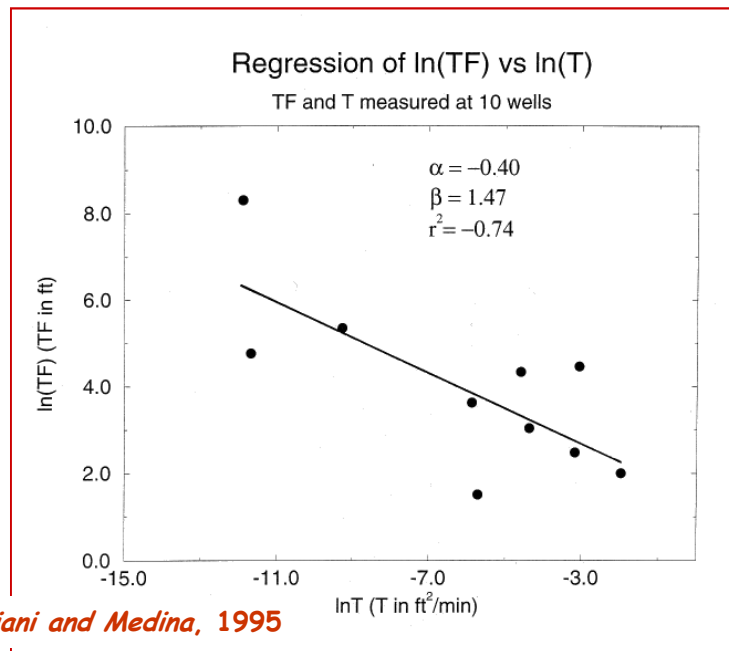


In passato:

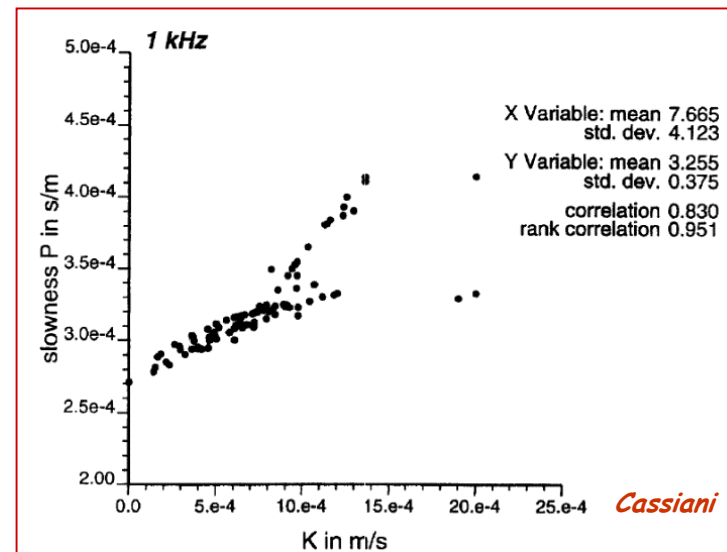
Ricerca di relazioni dirette tra grandezze geofisiche (p.es. velocità sismica, resistività elettrica) e grandezze idrologiche (p.es. conduttività idraulica)



Mazac et al., 1985



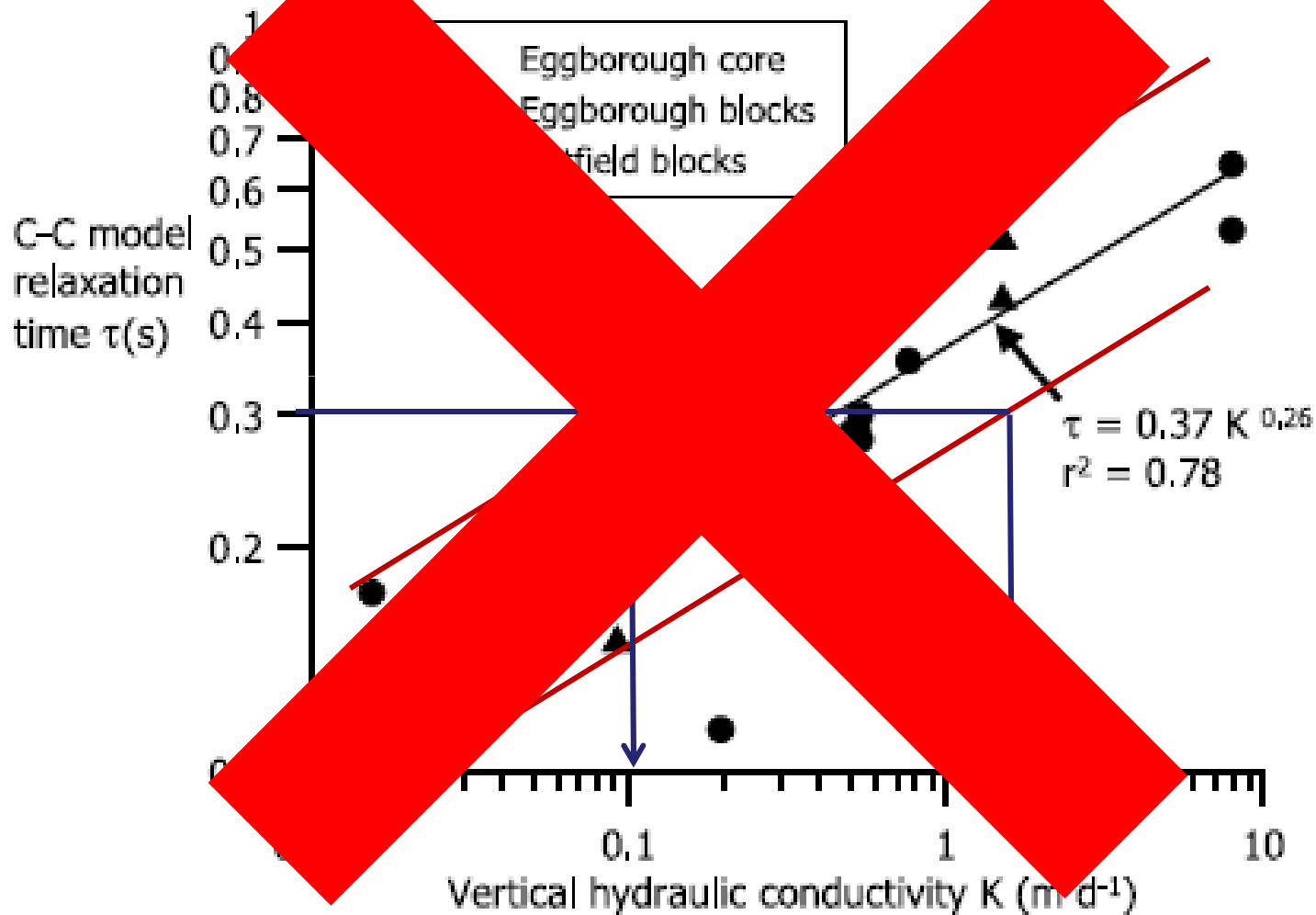
Cassiani and Medina, 1995

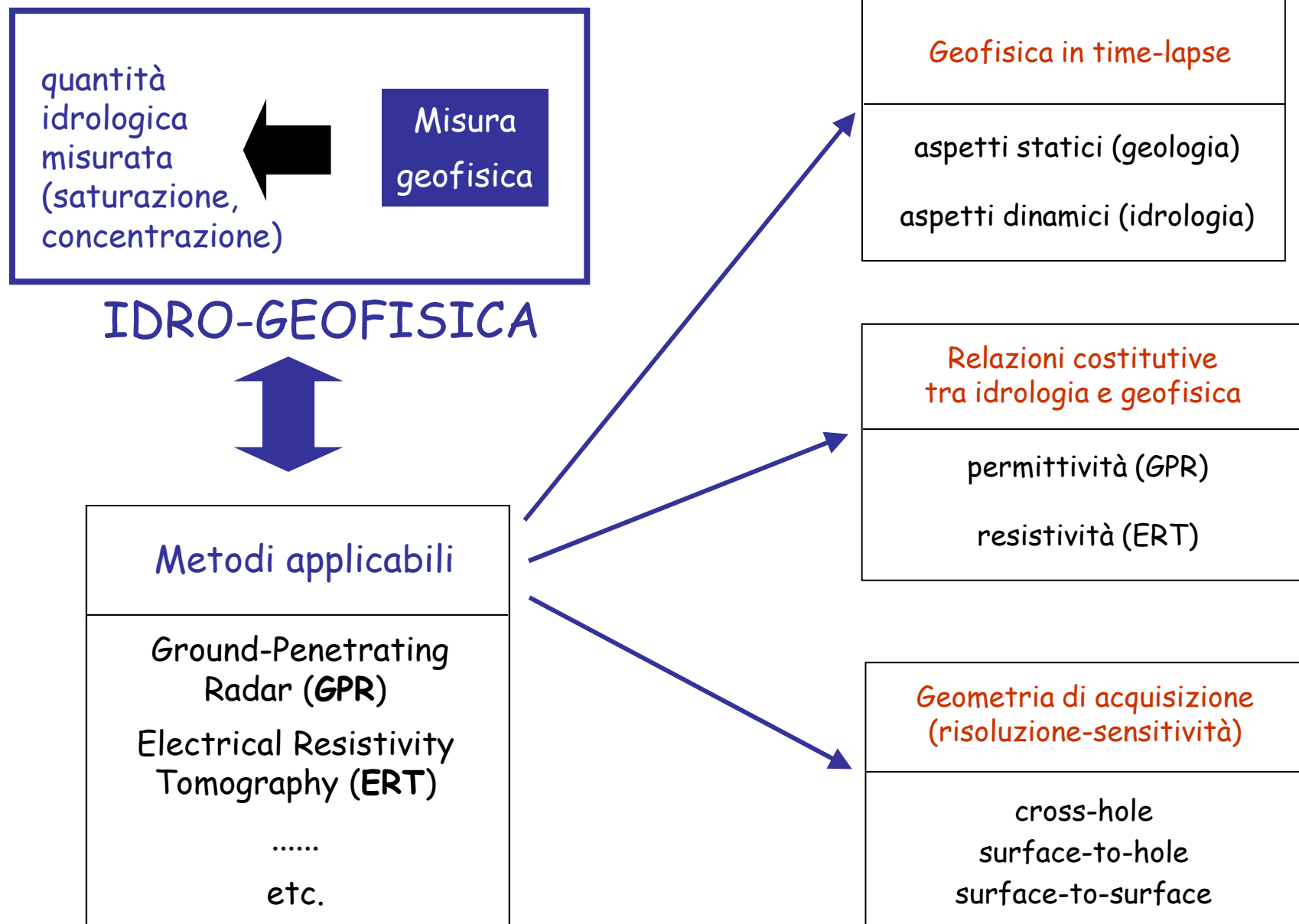


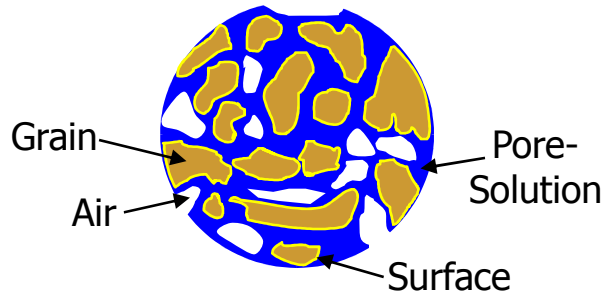
Cassiani et al., 1998



Relazione tra polarizzazione indotta e conduttività idraulica





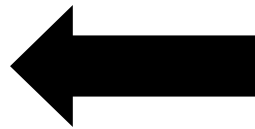


Constitutive relationships are necessary to link (combinations of) measured geophysical parameters to the soil/subsurface characteristics of interest.

GEOFYSICS

electrical resistivity
electrical permittivity
etc...

⋮

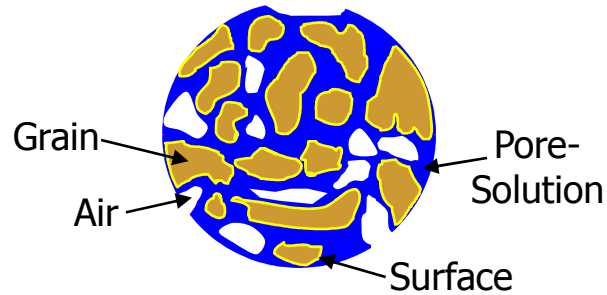


soil structure

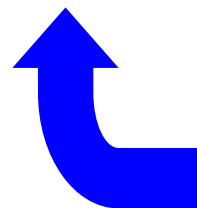
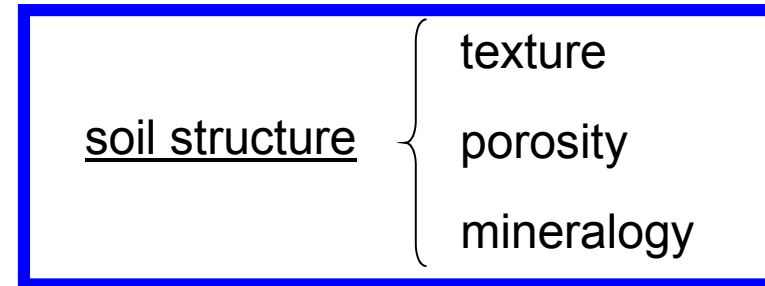
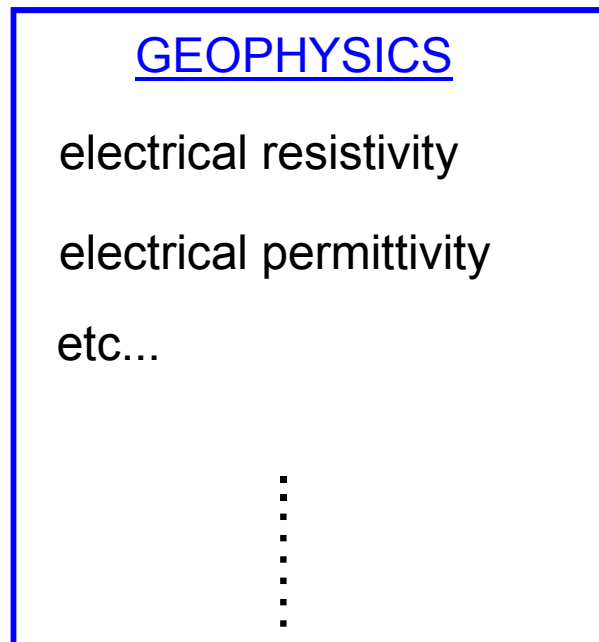
{ texture
porosity
mineralogy

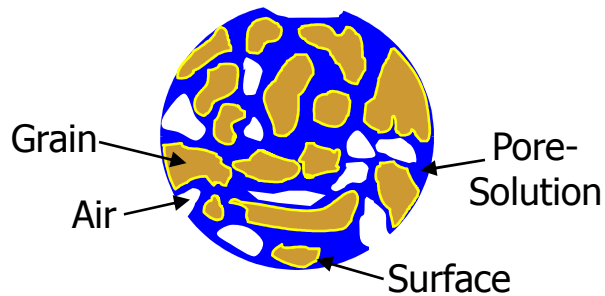
ambient dynamics

{ moisture content
temperature



Constitutive relationships are necessary to link (combinations of) measured geophysical parameters to the soil/subsurface characteristics of interest.



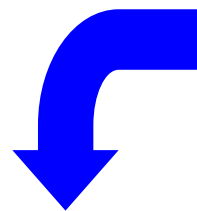


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electrical resistivity
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⋮



soil structure

{ texture
porosity
mineralogy



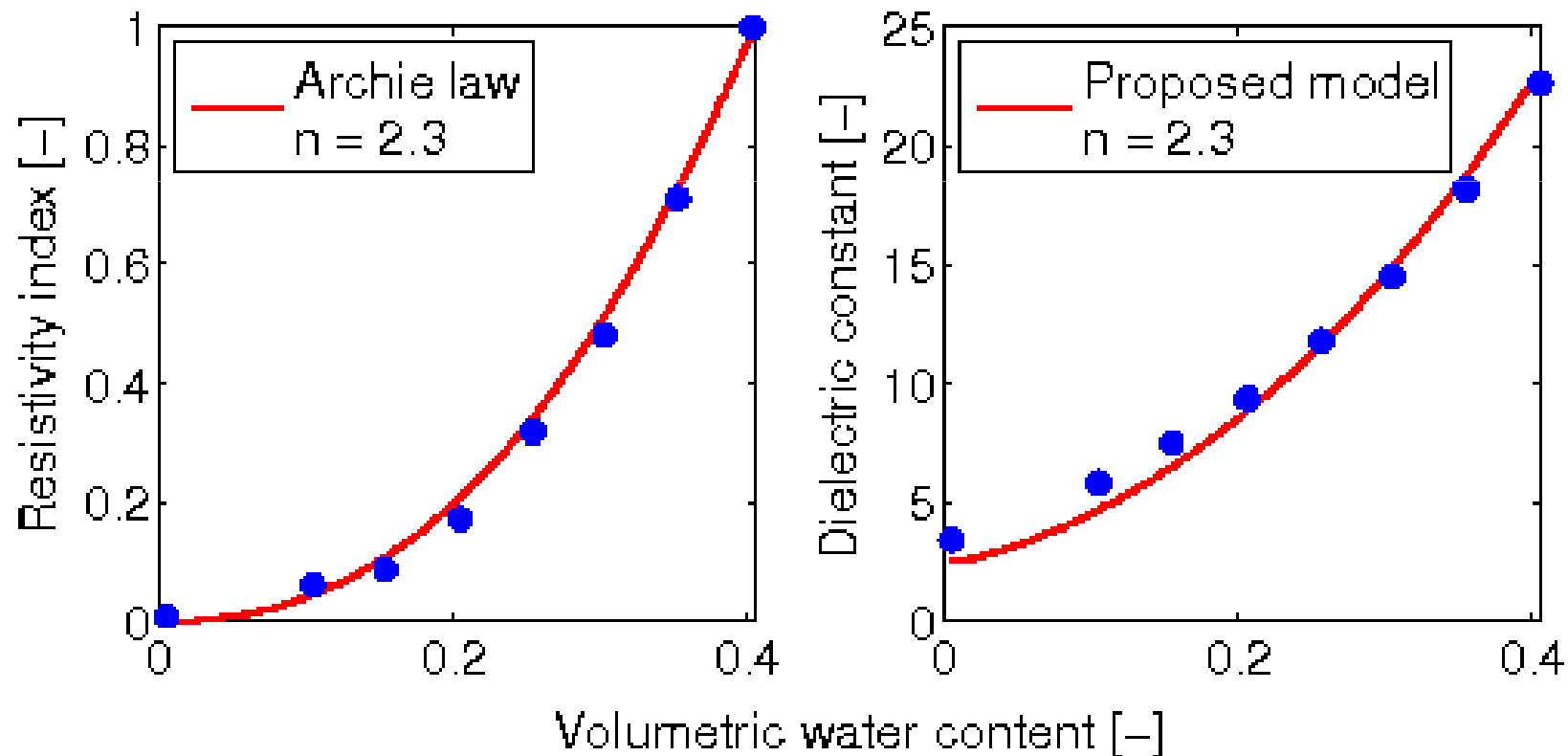
ambient dynamics

{ moisture content
temperature



Constitutive laws: resistivity and permittivity

Note: with the **same parameters** it is possible to describe **both** electrical conductivity and dielectric constant.







ESEMPI



VELOCITA' DI FILTRAZIONE



DINAMICA DI PENDIO



CONNESSIONE TRA FALDE ACQUIFERE



DINAMICA DEL NON SATURO



ZONA IPOREICA



LIQUEFAZIONE: STIMA DI POROSITA'



STRUTTURE ARGINALI

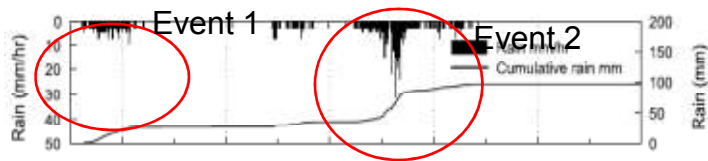


Conclusioni



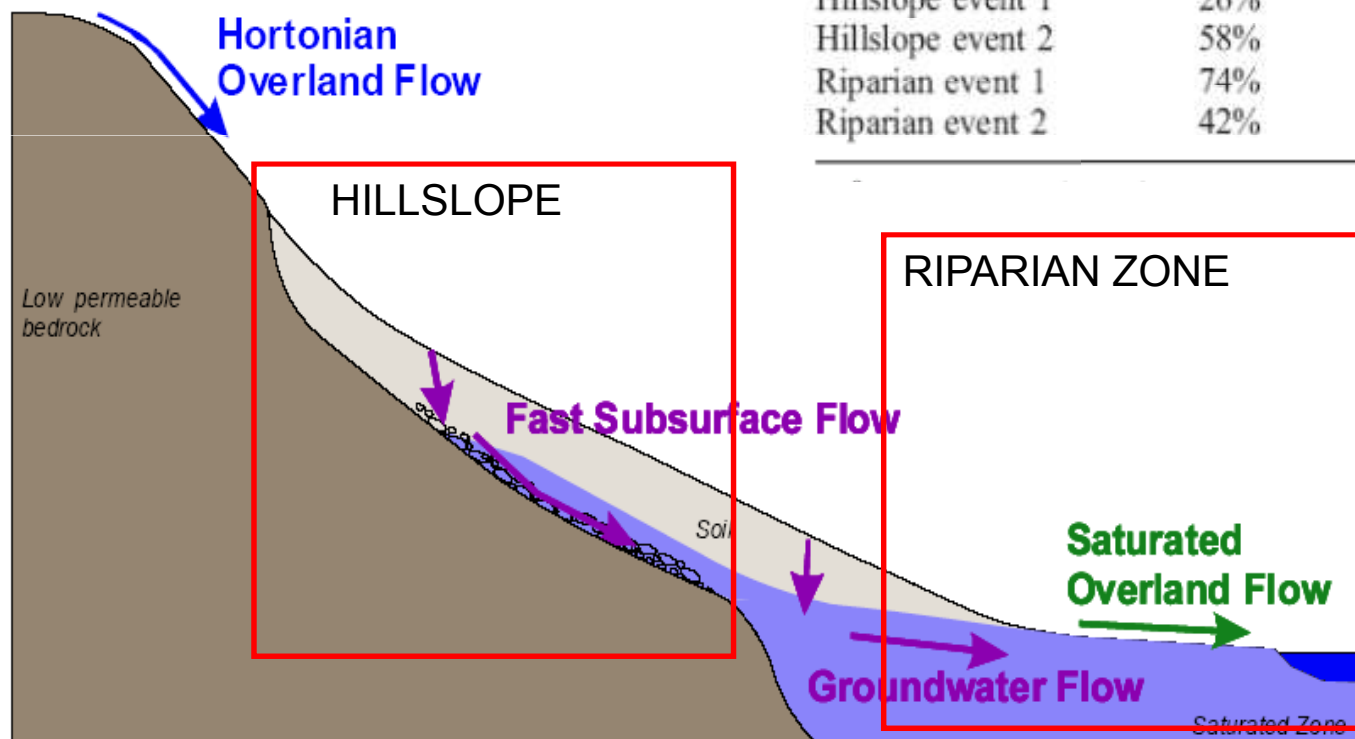


Acqua “vecchia” e acqua “nuova”



Three-Component Separation
New/Old Riparian/Old Hillslope)
(3CompHS)

Event 1	19%/55%/26%
Event 2	21%/23%/56%
Hillslope event 1	26%
Hillslope event 2	58%
Riparian event 1	74%
Riparian event 2	42%



McGlynn and McDonnell, 2003



Sito sperimentale di Montemezzo (CO)

Obiettivo: caratterizzare la struttura e l'idrologia dei versanti di un piccolo bacino montano affetto da frane per scivolamento e soprattutto rischio alluvione



Sito sperimentale di Montemezzo

(Cassiani et al., 2009, *Near Surface Geophysics*
Strobbia and Cassiani, 2007, *Geophysics*)



Descrizione del sito



quota: 1150 m s.l.m.
pendenza: 30-40 gradi
copertura di suolo: spessore di 1-2 m, morena
sabbioso-ghiaiosa; conducibilità idraulica medio
bassa (10^{-6} m/s)
basamento: paragneiss con foliazione sub-verticale,
friabile.
vegetazione: erba, con bosco circostante di faggi e
betulle

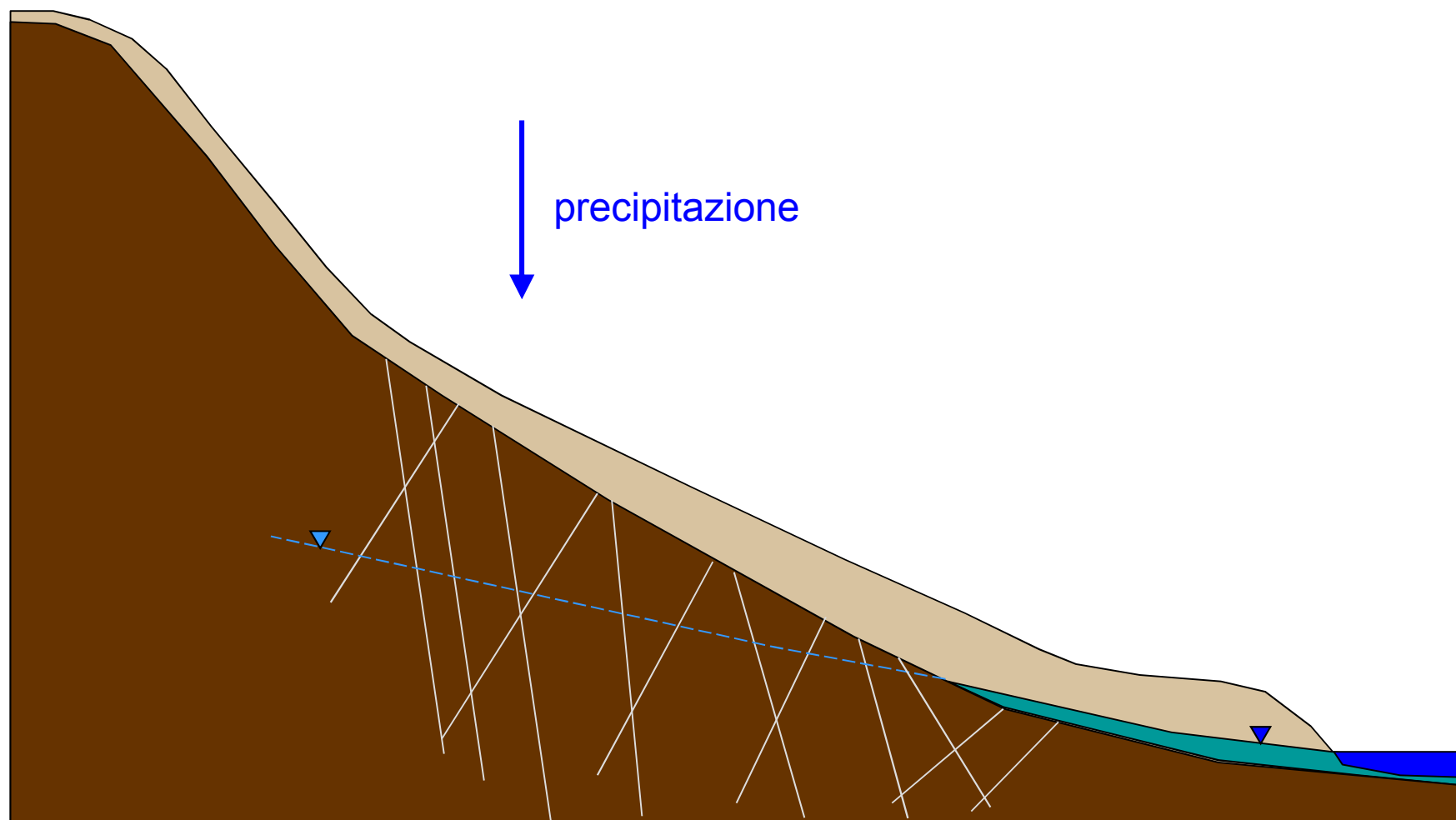
CAPPELLA
DELL' ALLUVIONE

8 AGOSTO 1951

Grave rischio di inondazione

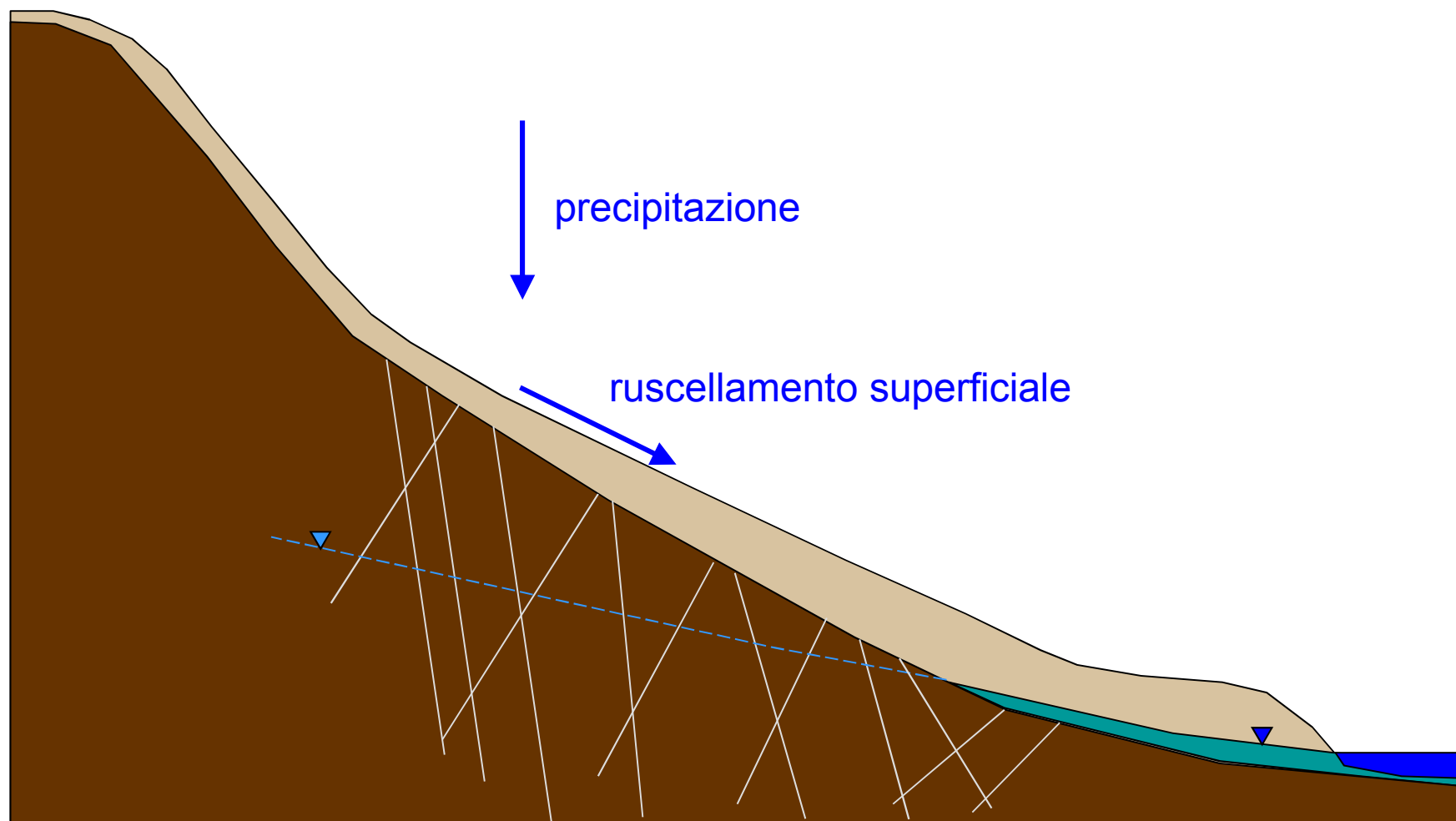


Acqua “vecchia” o acqua “nuova” ?



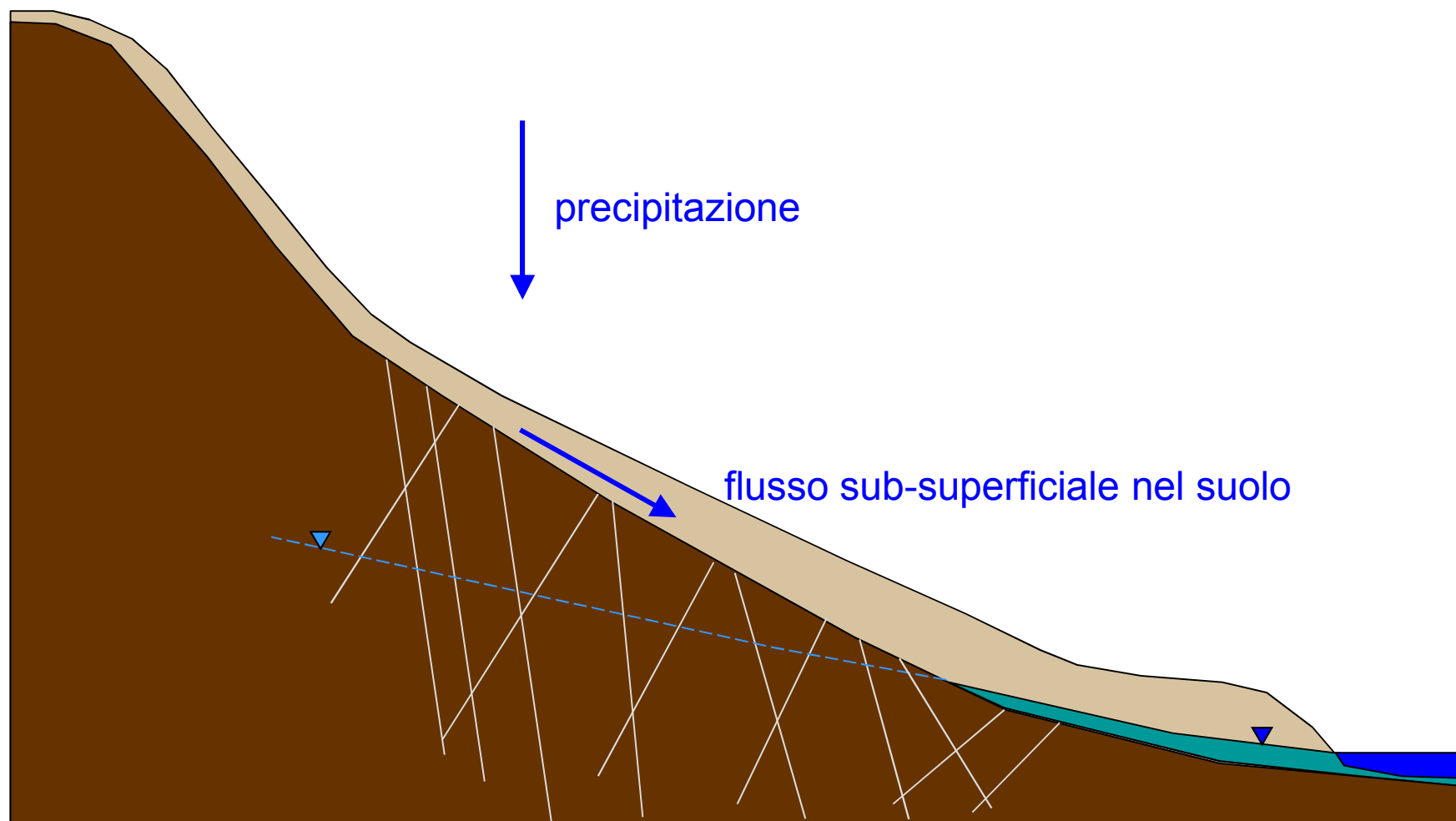


Acqua “vecchia” o acqua “nuova” ?



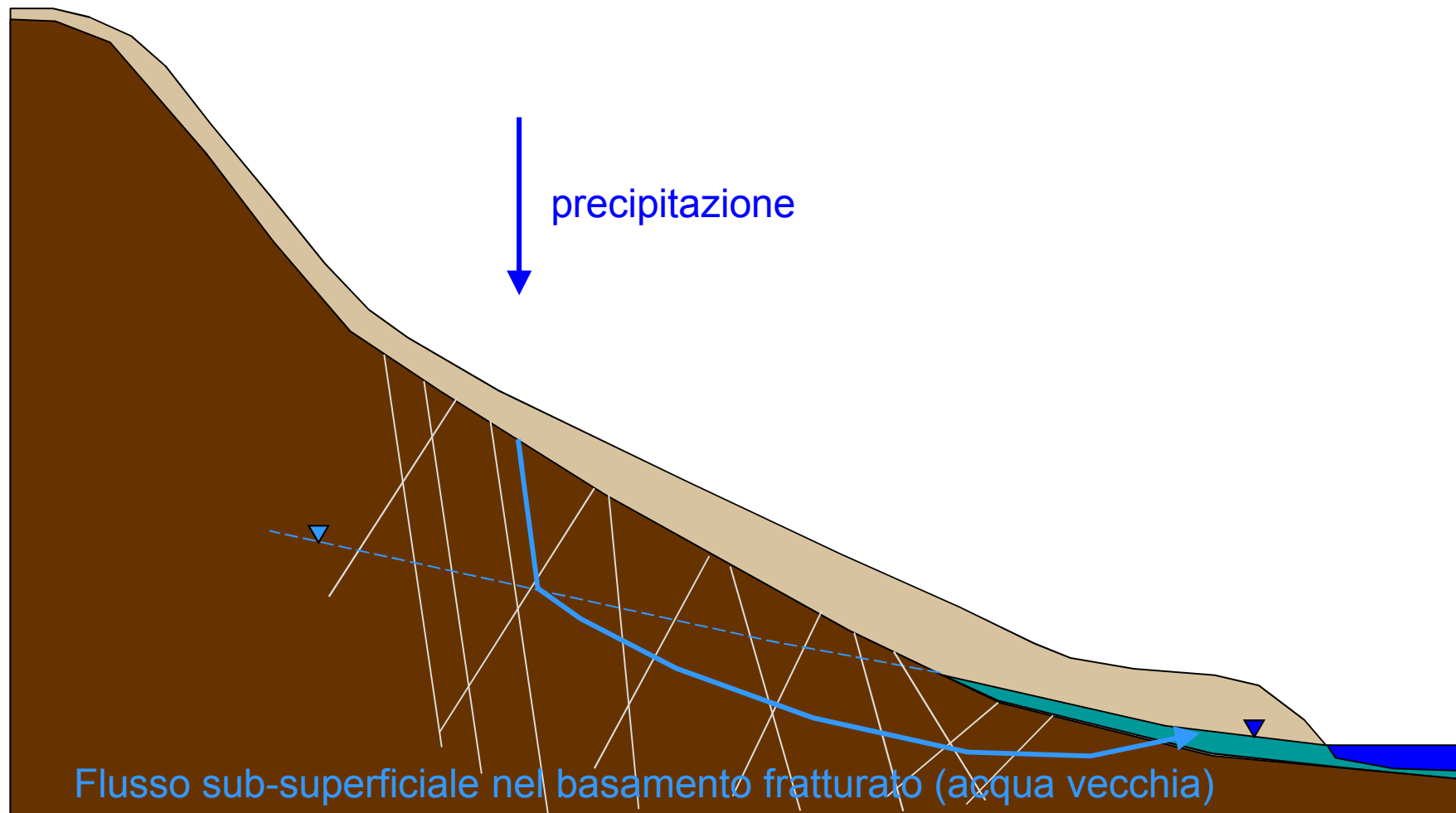


Acqua “vecchia” o acqua “nuova” ?





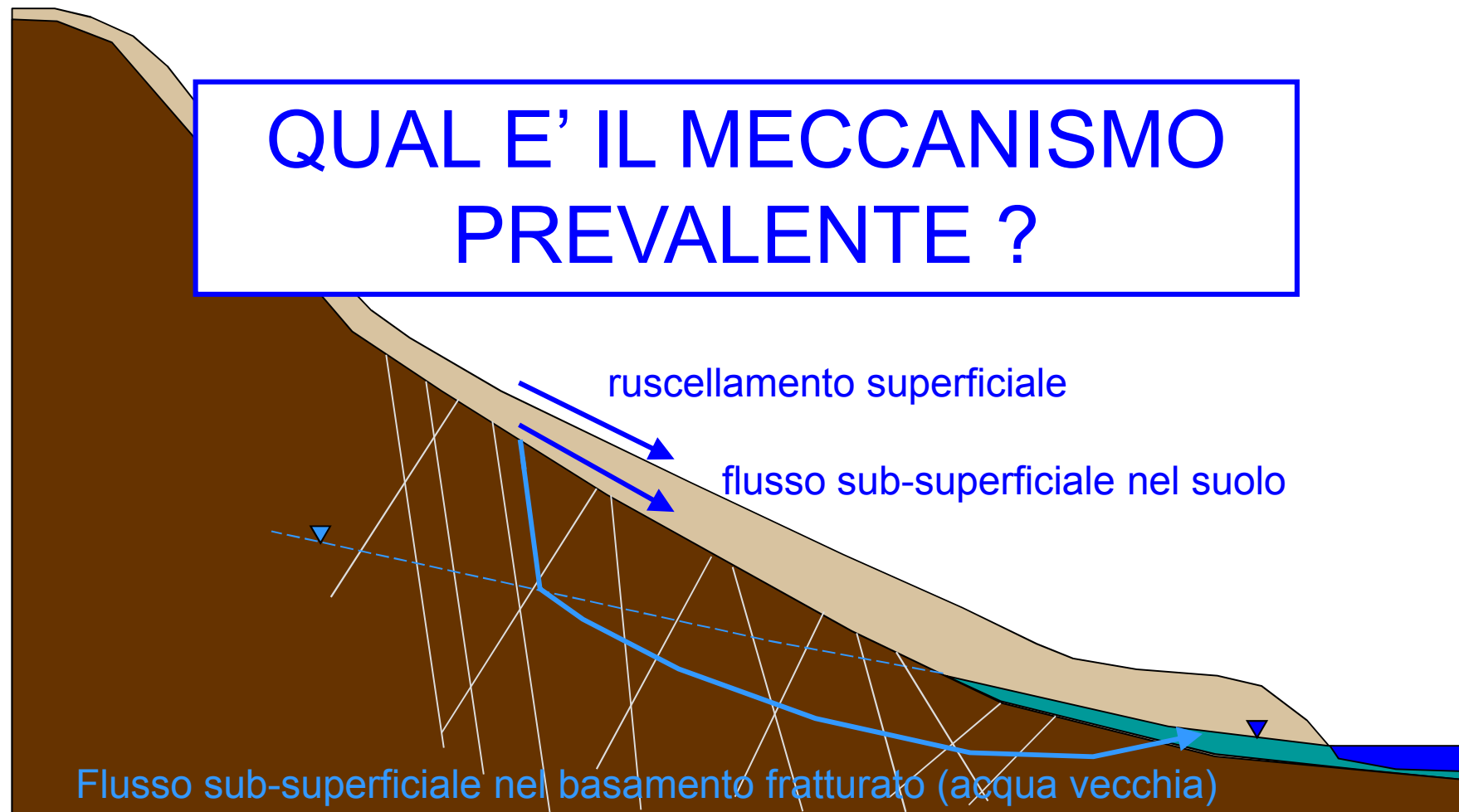
Acqua “vecchia” o acqua “nuova” ?

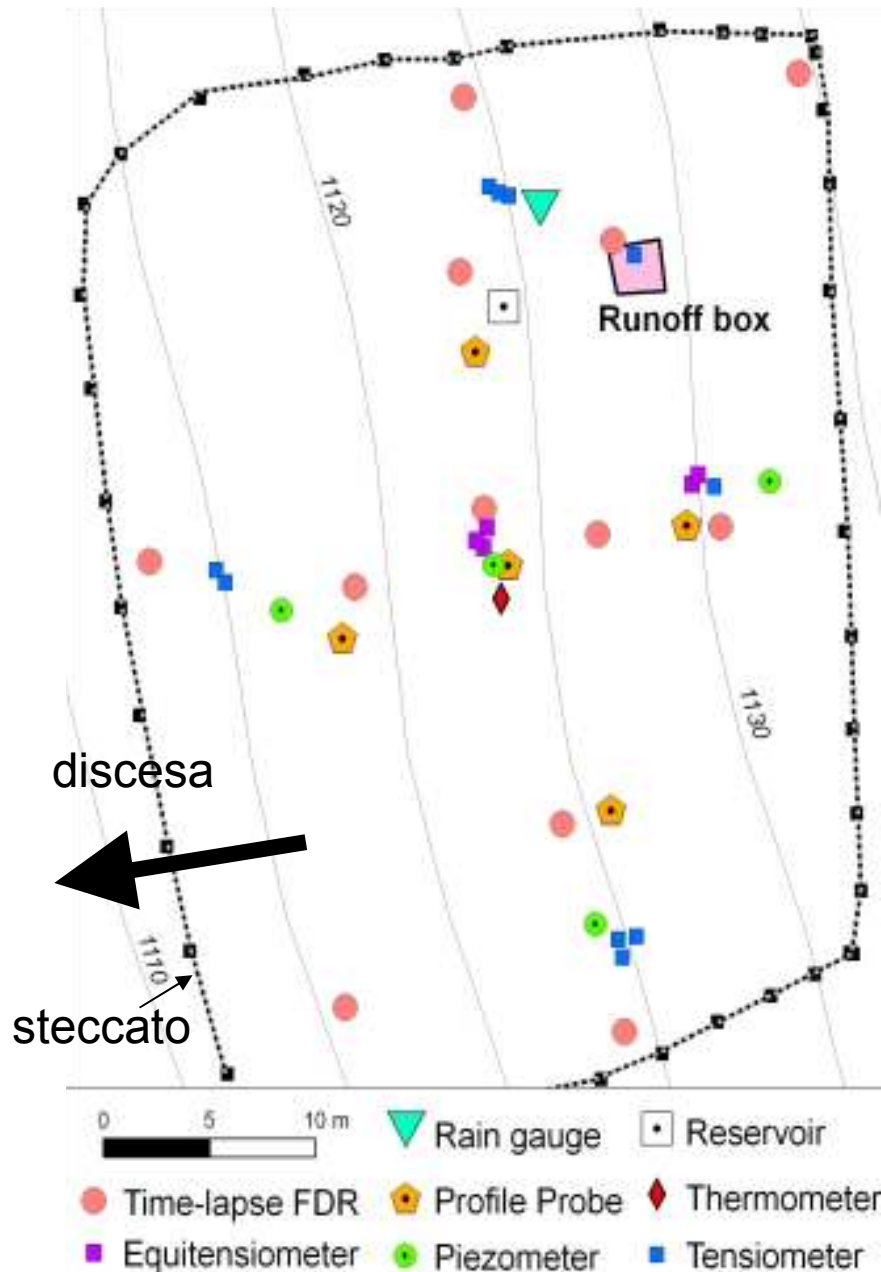




Acqua “vecchia” o acqua “nuova” ?

QUAL E' IL MECCANISMO
PREVALENTE ?



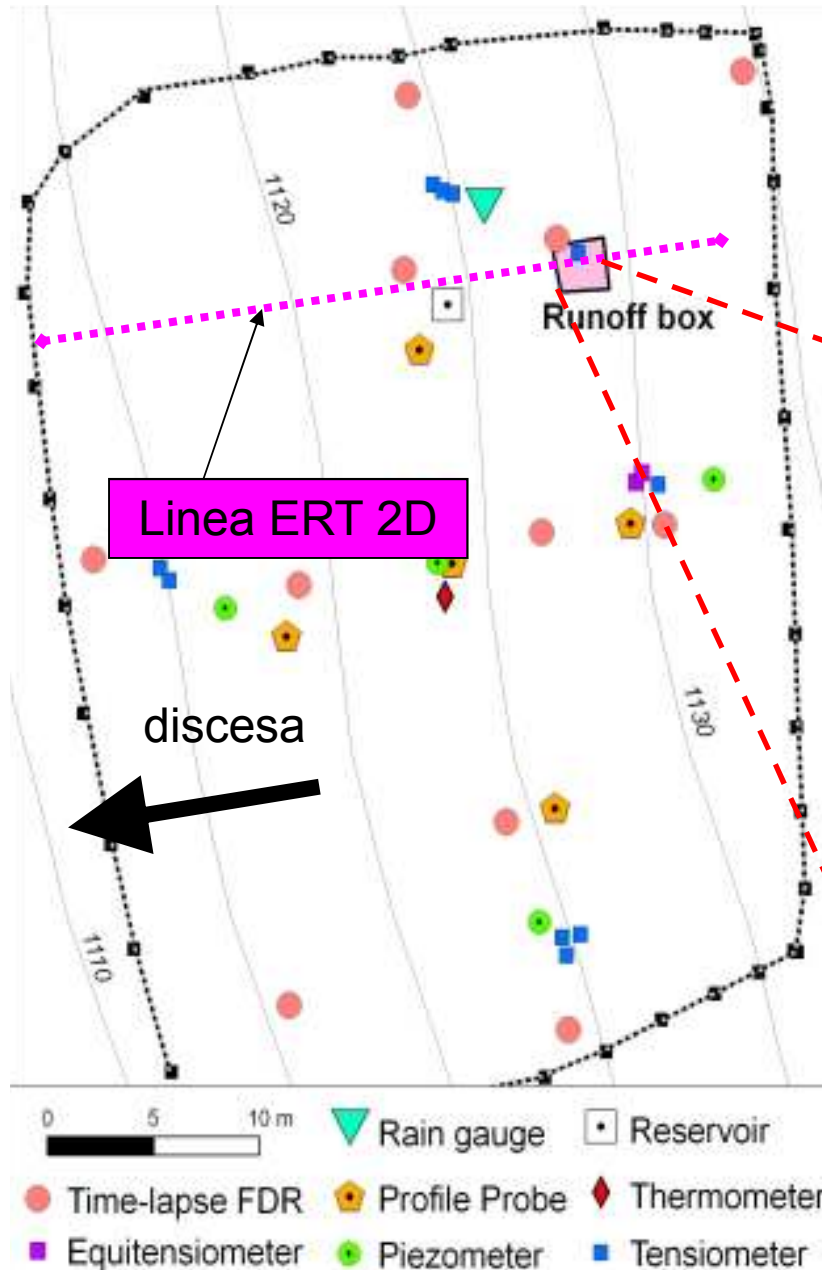


Stazione di monitoraggio idrologico



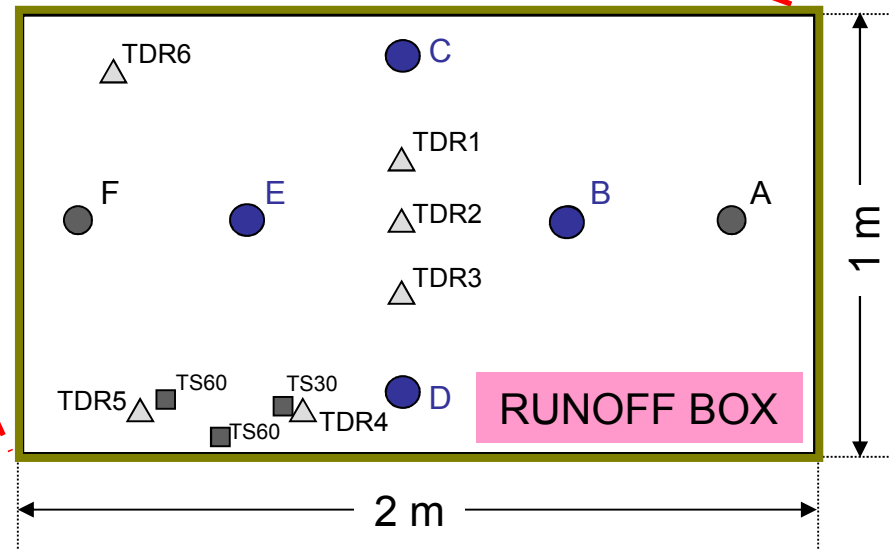
A partire dal 2003 è stata condotta una campagna di monitoraggio di lungo termine, con misure di:

- precipitazione,
- ruscellamento superficiale,
- temperatura del suolo,
- contenuto idrico del suolo.



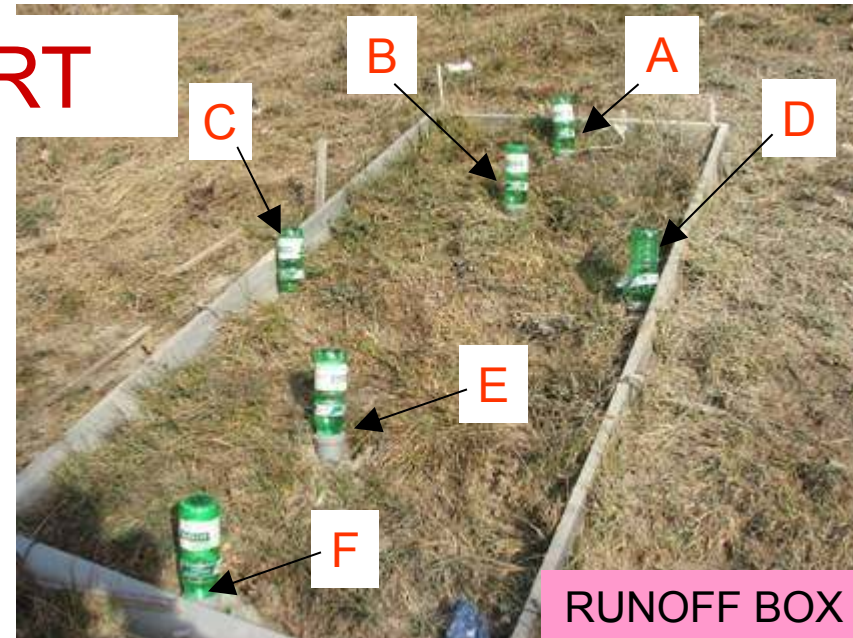
Test di irrigazione

Nel 2006 e nel 2007 sono stati condotti due test di irrigazione su una runoff box, equipaggiata con TDR, tensiometri e fori attrezzati con elettrodi per ERT.

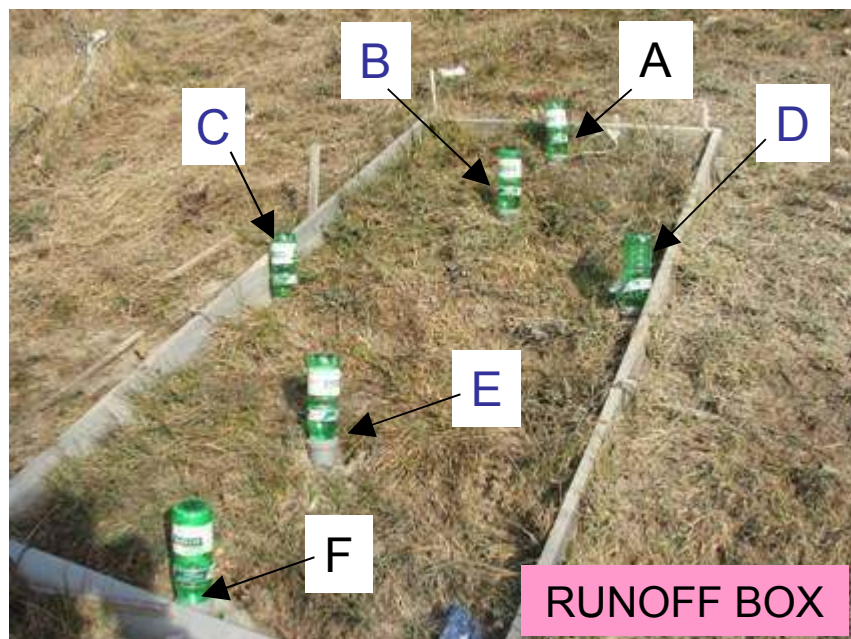




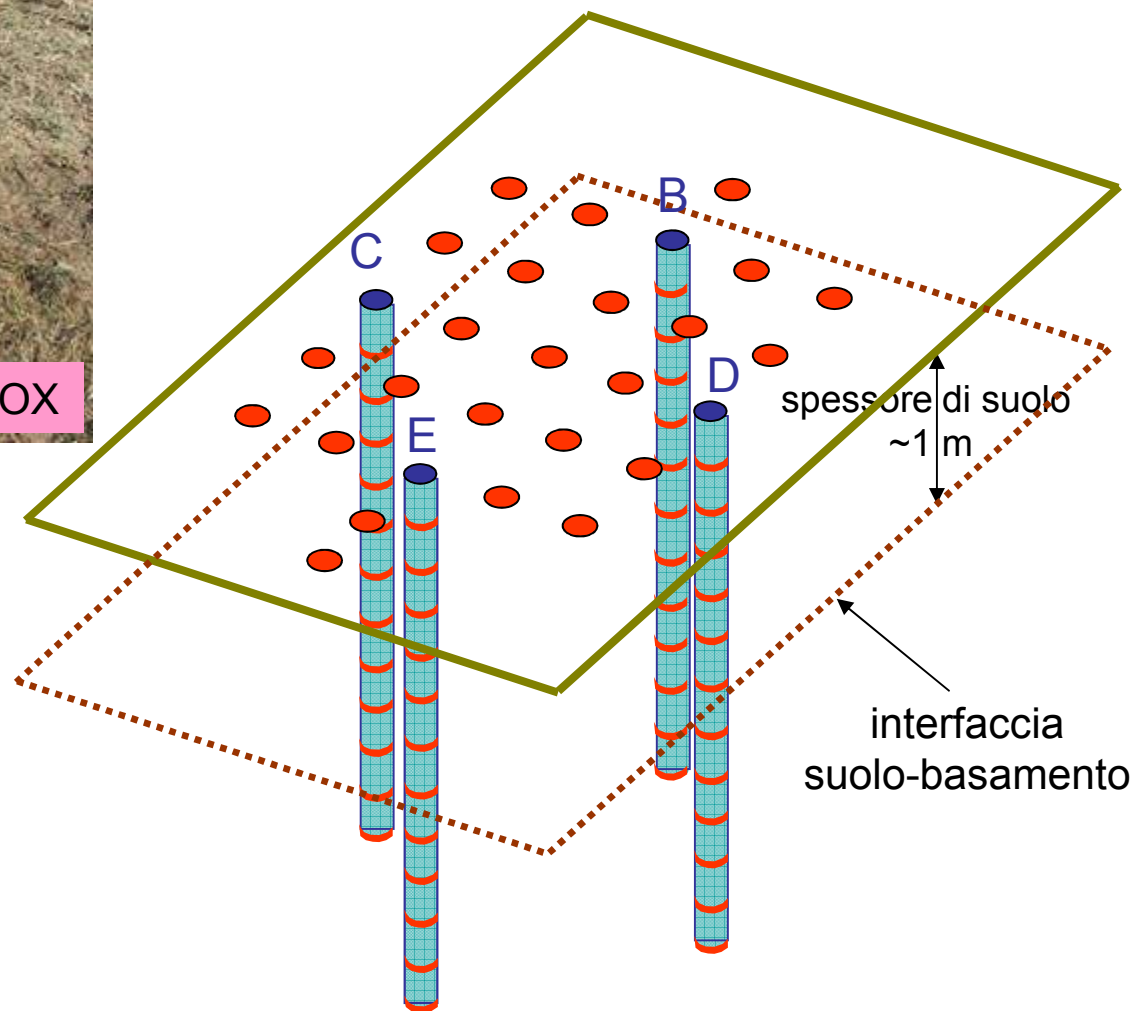
Istallazione dei fori ERT



Sei fori profondi 2 m.
12 elettrodi in ciascun foro.

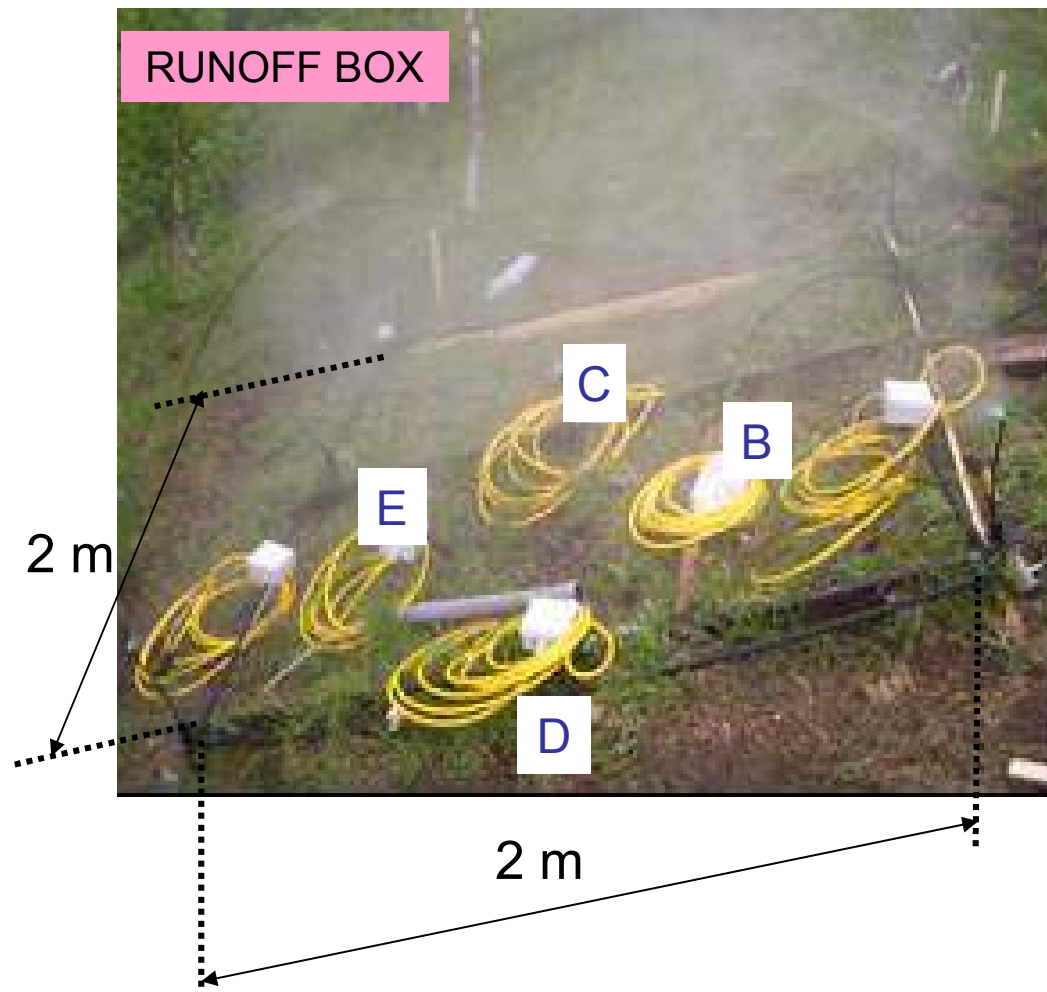


4D (time-lapse) ERT



- ❑ 72 elettrodi (12 in ognuno di 4 fori + 24 elettrodi da superficie)
- ❑ schema di acquisizione dipolo-dipolo skip 0, con reciproci
- ❑ tempo di acquisizione di circa 40 min per ogni time step con un IRIS Syscal Pro.
- ❑ per l'inversione è stato usato il codice R3 (A.M.Binley – Lancaster University)

Test di irrigazione

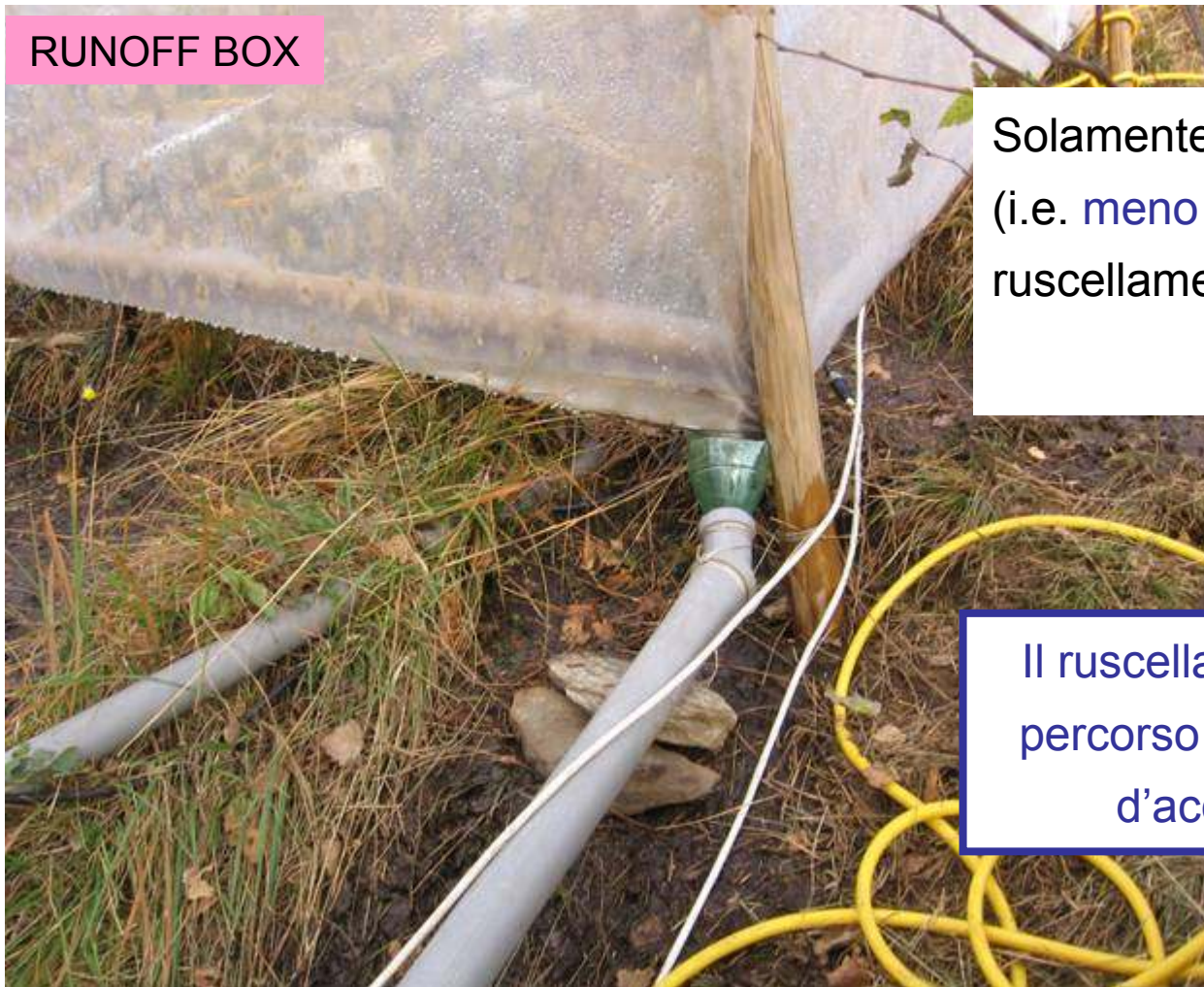


- ❑ Il **29 ottobre 2007**, sono stati applicati **9330 litri** di pioggia artificiale su un'area di **2 m x 2 m** per **18 ore** (equivalenti a una pioggia di 2500 mm).
- ❑ L'infiltrazione è stata stimata sottraendo il **ruscellamento misurato**.
- ❑ Date le condizioni meteo ed il ridotto periodo di irrigazione l'**evapo-transpirazione** è stata trascurata.



Misure di ruscellamento

RUNOFF BOX



Solamente 640 litri dei 9330 totali (i.e. **meno del 7%**) sono andati in ruscellamento superficiale.



Il ruscellamento superficiale è un percorso trascurabile per il flusso d'acqua lungo il pendio.



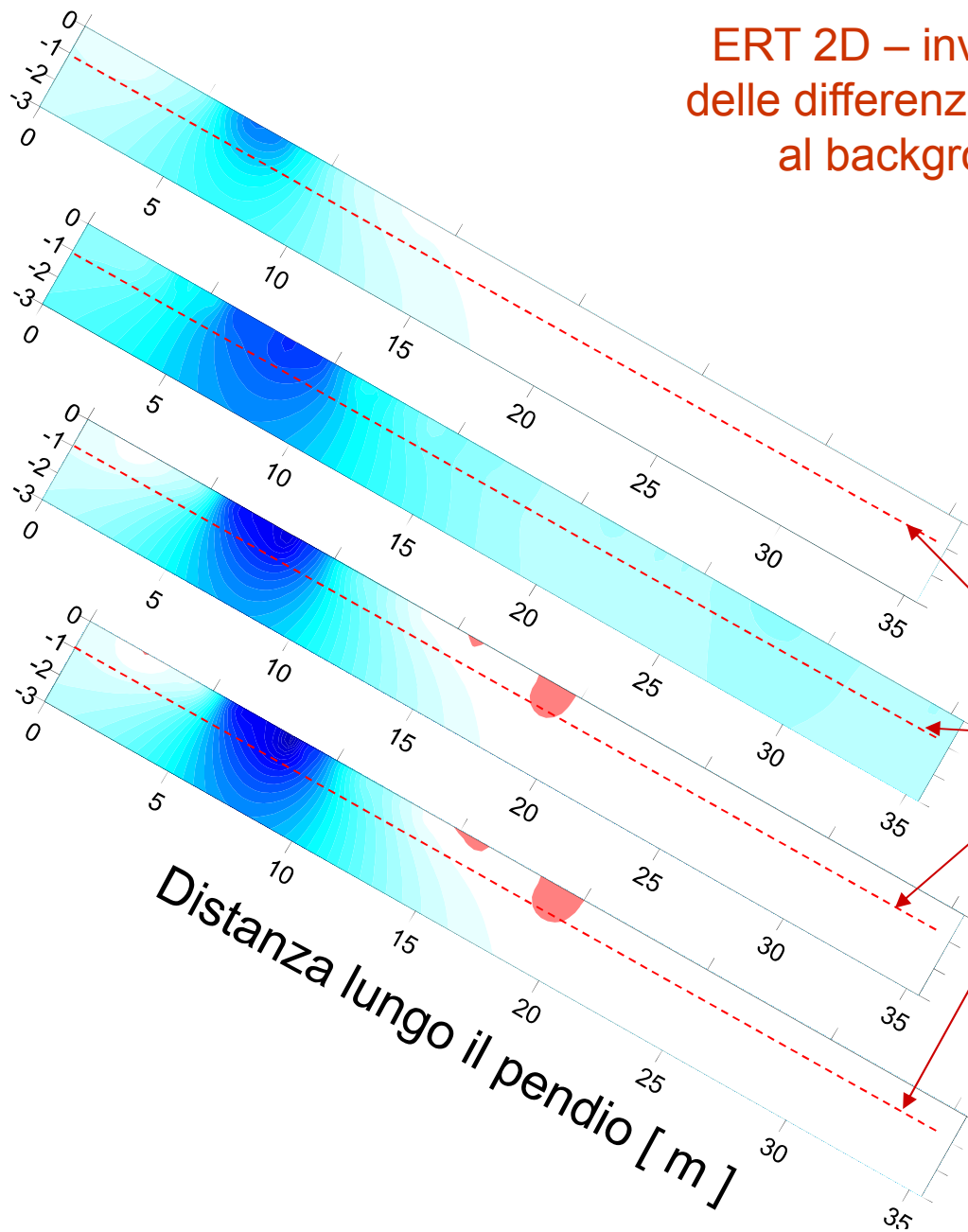
dopo 1.2 h

dopo 3 h

dopo 5 h

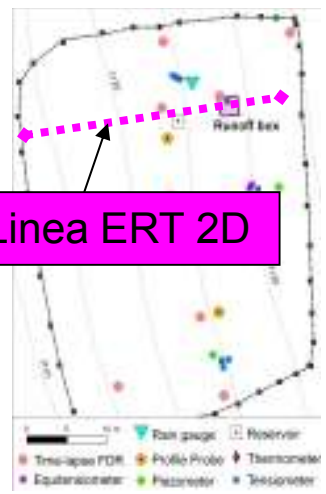
dopo 10 h

ERT 2D – inversione delle differenze rispetto al background



interfaccia suolo-basamento

% di variazione rispetto alla resistività di background



Linea ERT 2D



FINE IRRIGAZIONE

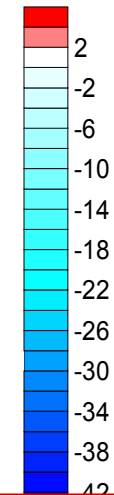
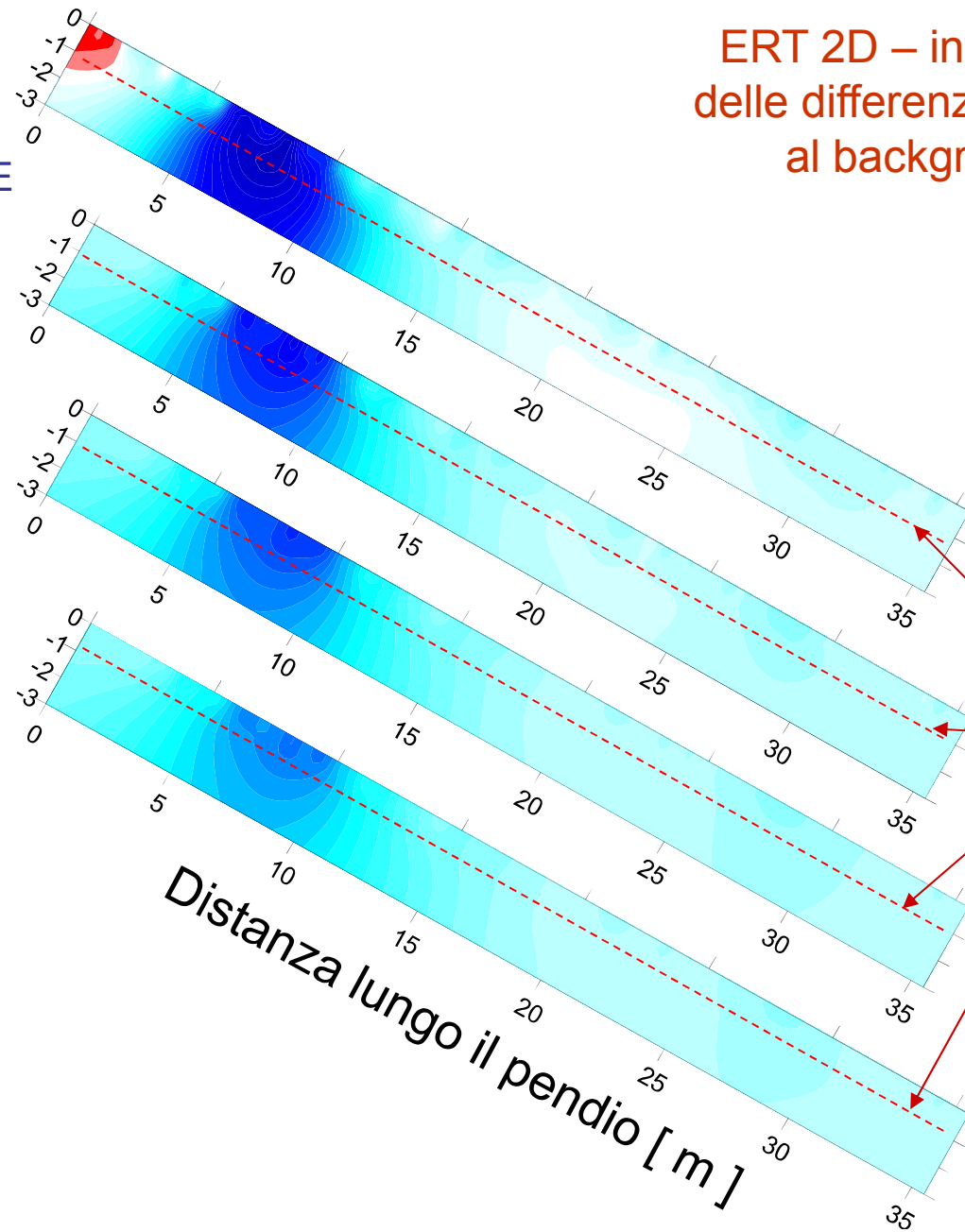
dopo 18 h

dopo 19 h

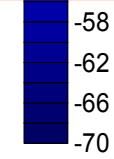
dopo 21 h

dopo 26 h

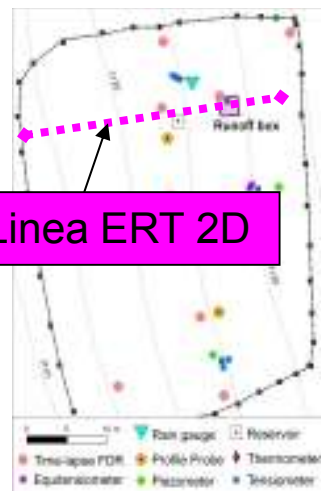
ERT 2D – inversione delle differenze rispetto al background



interfaccia suolo-basamento



% di variazione rispetto alla resistività di background



Linea ERT 2D

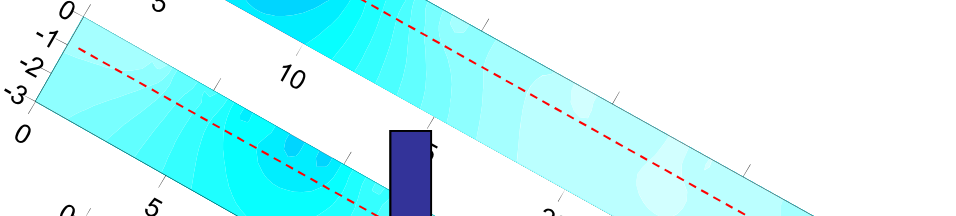


dopo 32 h

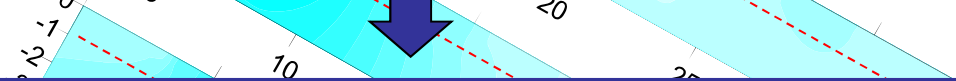


ERT 2D – inversione delle differenze rispetto al background

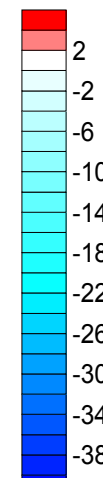
dopo 42 h



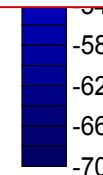
dopo 44 h



Il flusso subsuperficiale nel suolo è un percorso trascurabile per l'acqua lungo il pendio.



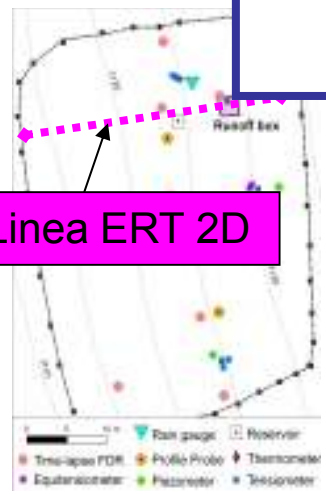
interfaccia suolo-basamento



% di variazione rispetto alla resistività di background

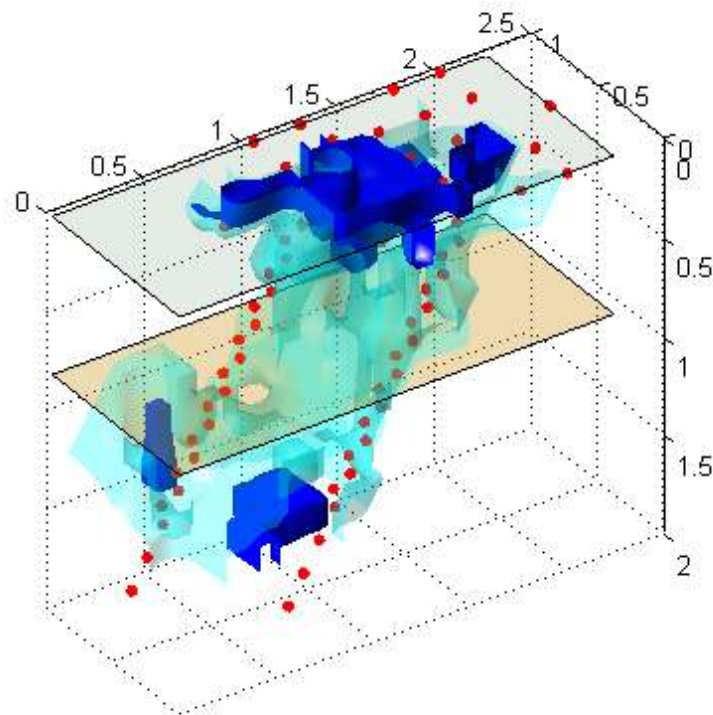
Distanza lungo il pendio [m]

Linea ERT 2D

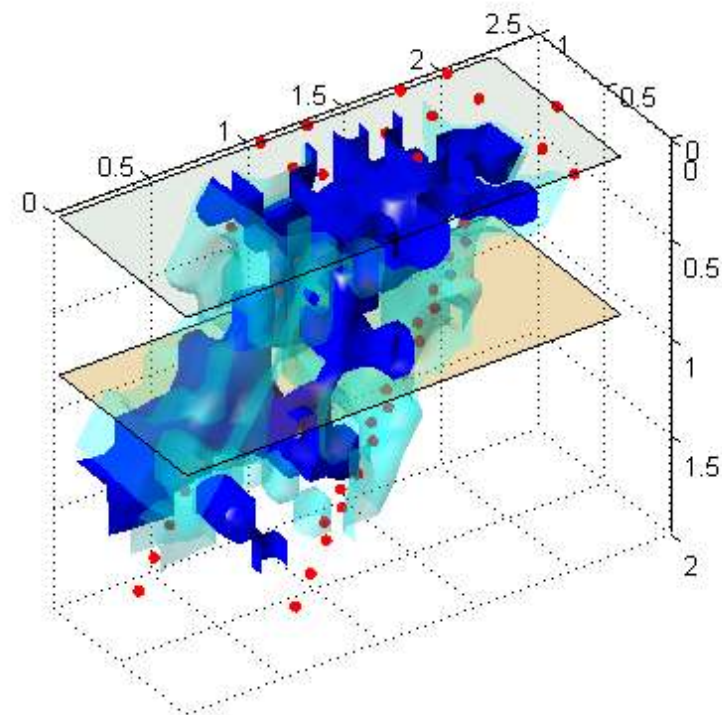




3D ERT inversione di resistività rispetto al background



dopo 0.8 h



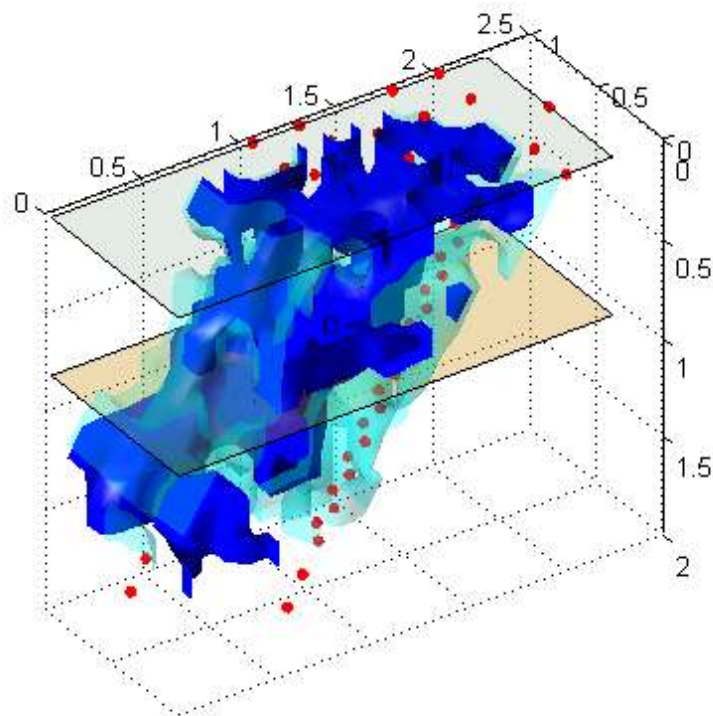
dopo 2.4 h

blu = 30% del background, azzurro = 70% del background

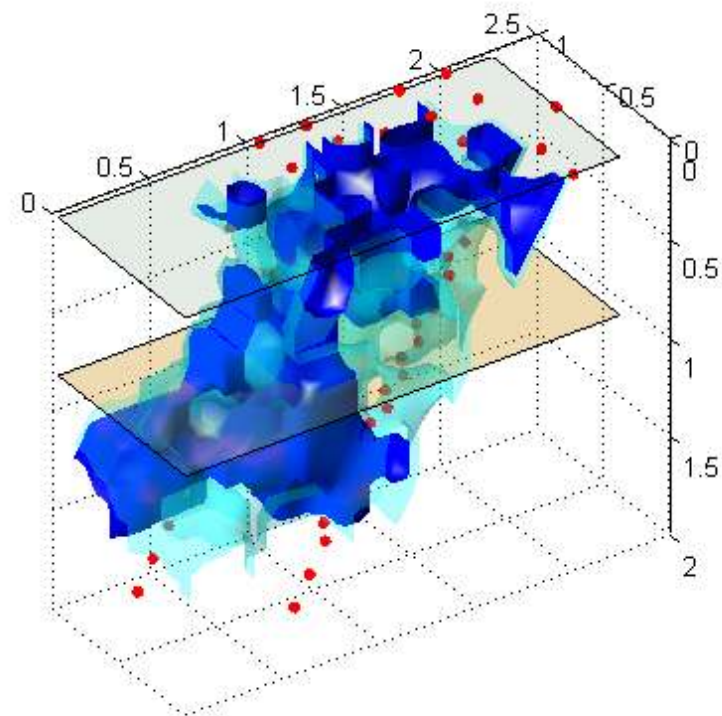


3D ERT

inversione di resistività rispetto al background



dopo 4.2 h



dopo 9.5 h

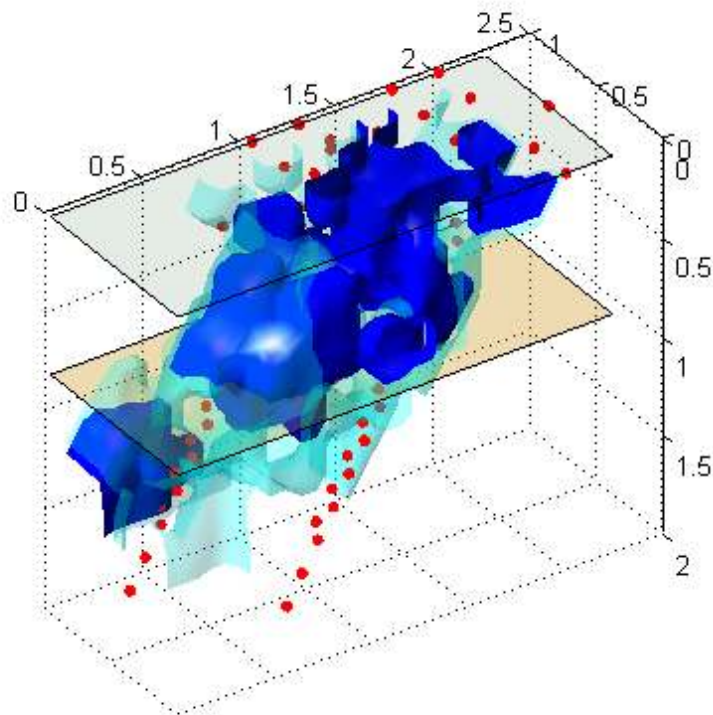
blu = 30% del background, azzurro = 70% del background



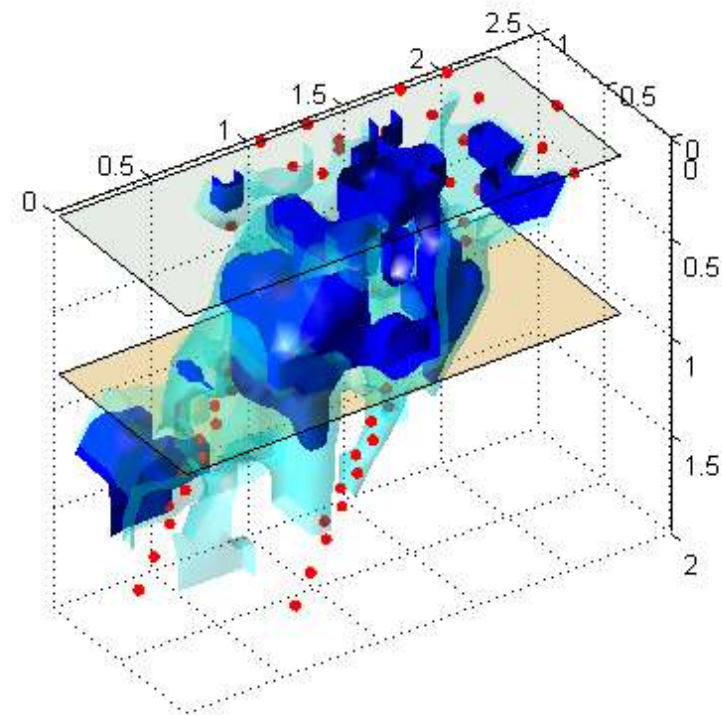
3D ERT

inversione di resistività rispetto al background

FINE IRRIGAZIONE



dopo 19.0 h



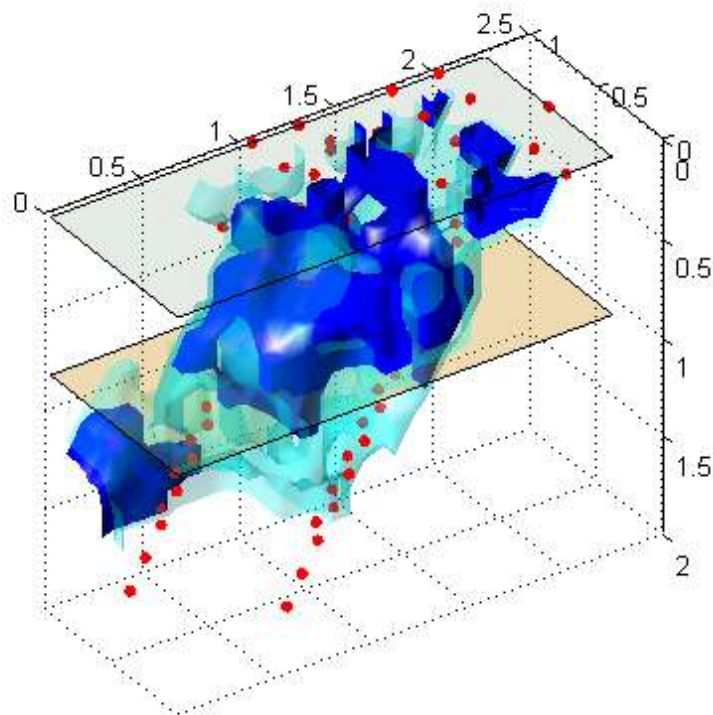
dopo 20.5 h

blu = 30% del background, azzurro = 70% del background

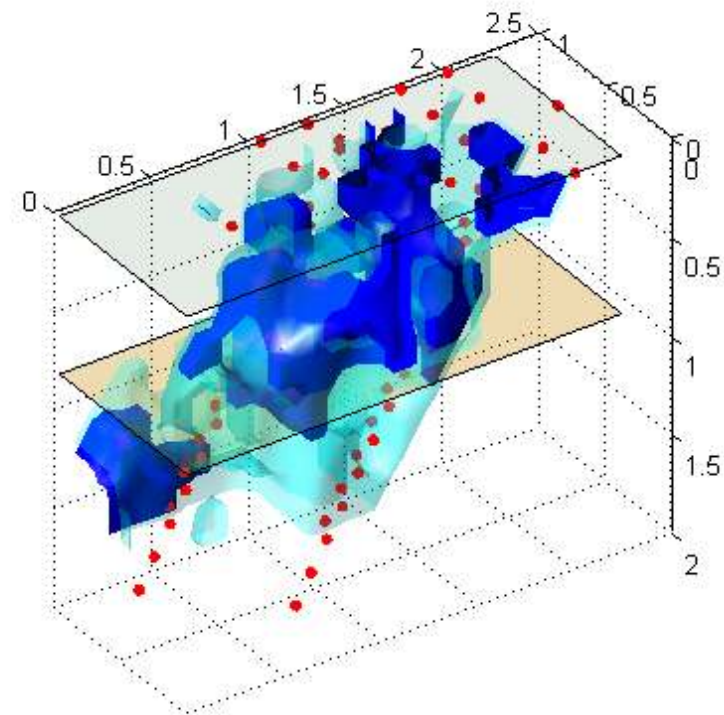


3D ERT

inversione di resistività rispetto al background



dopo 23.6 h

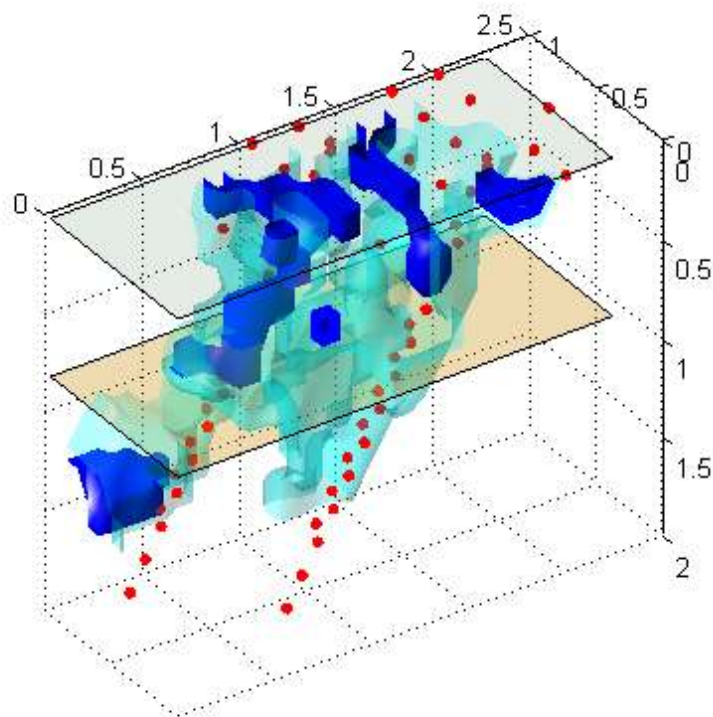


dopo 25.3 h

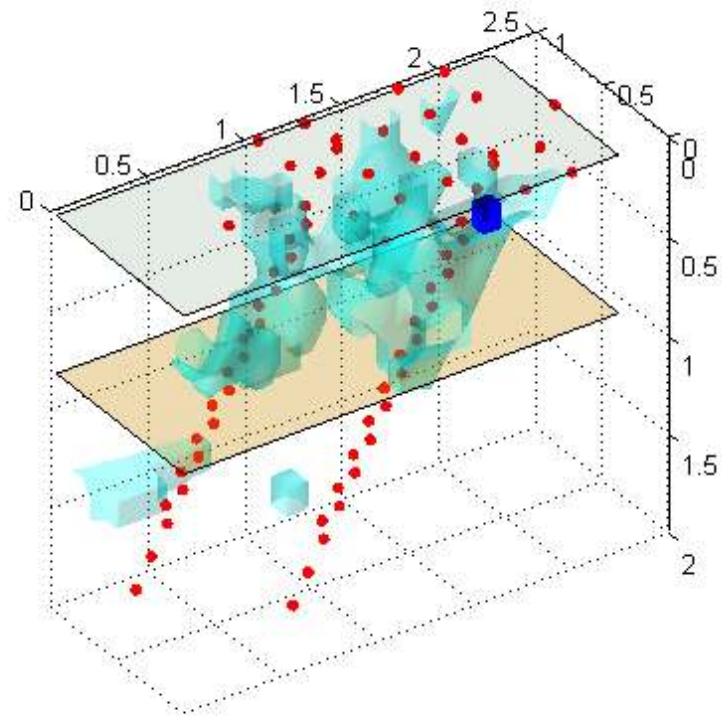
blu = 30% del background, azzurro = 70% del background



3D ERT inversione di resistività rispetto al background



dopo 47.2 h



dopo 214 h

blu = 30% del background, azzurro = 70% del background



Test con traccianti colorati



LE VIE PREFERENZIALI HANNO
UN RUOLO IMPORTANTE
NEI PROCESSI DI INFILTRAZIONE
IN QUESTO SUOLO

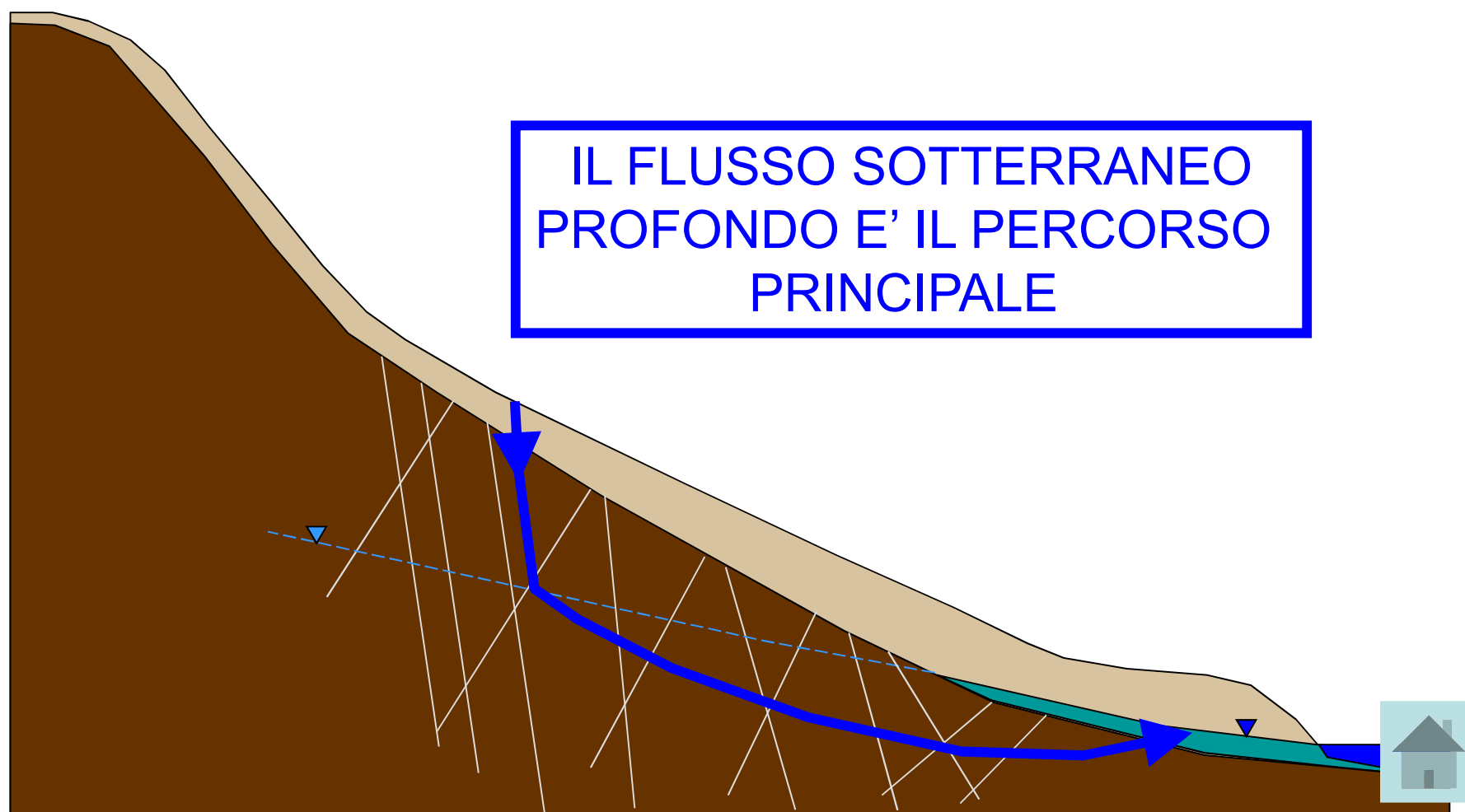
original picture

spectral analysis

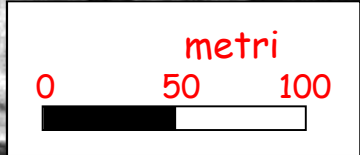
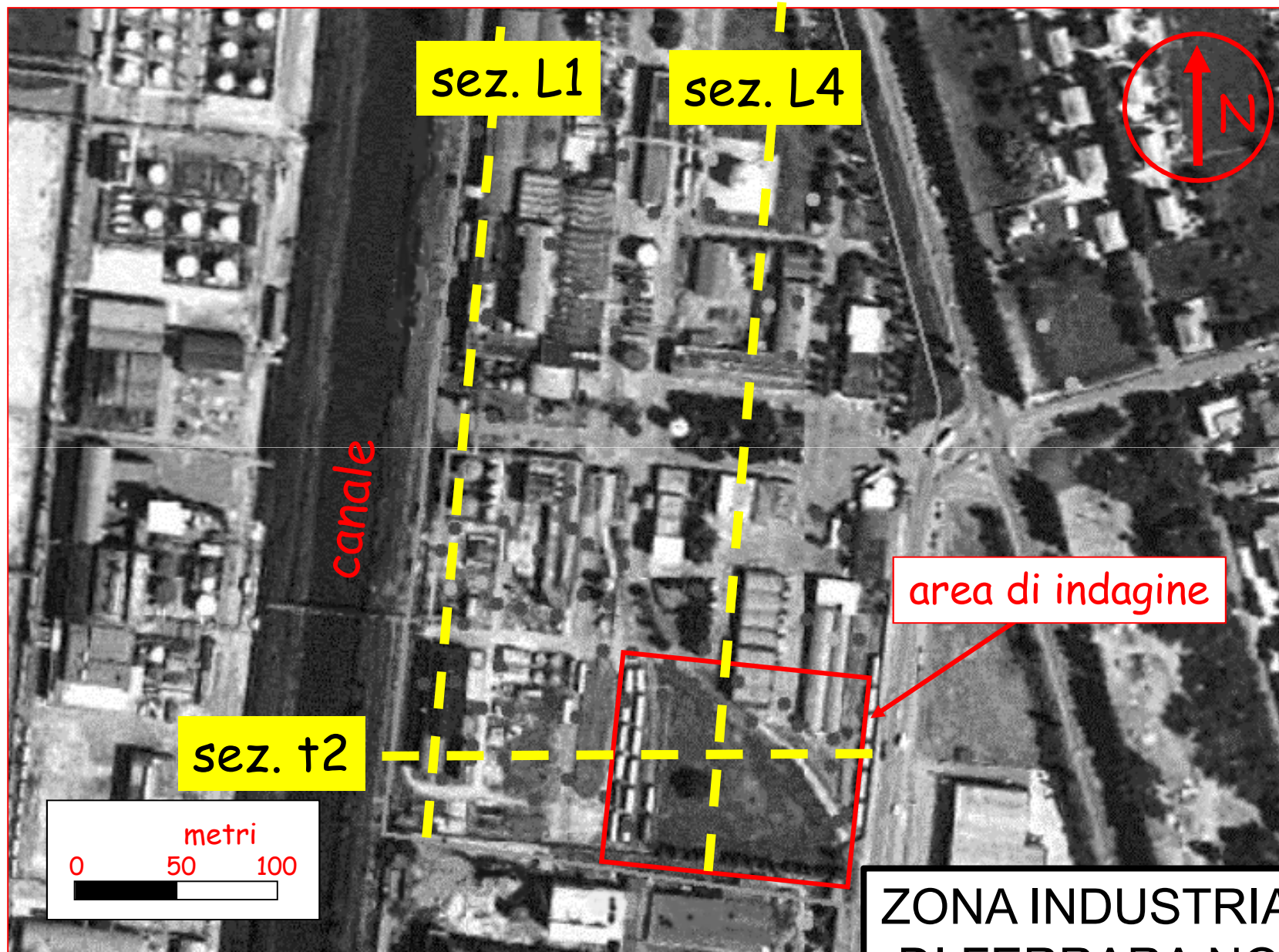
B/W thresholding



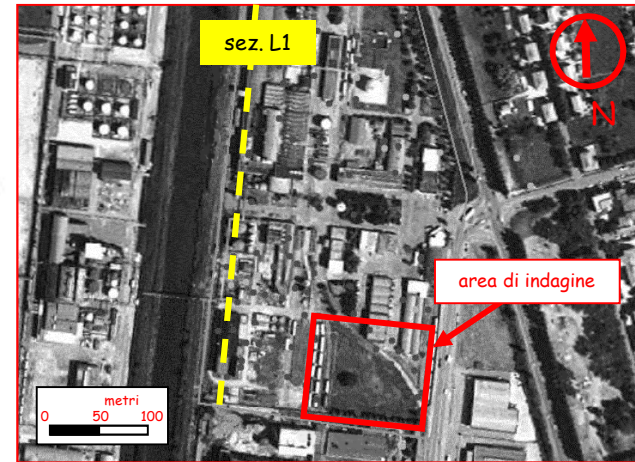
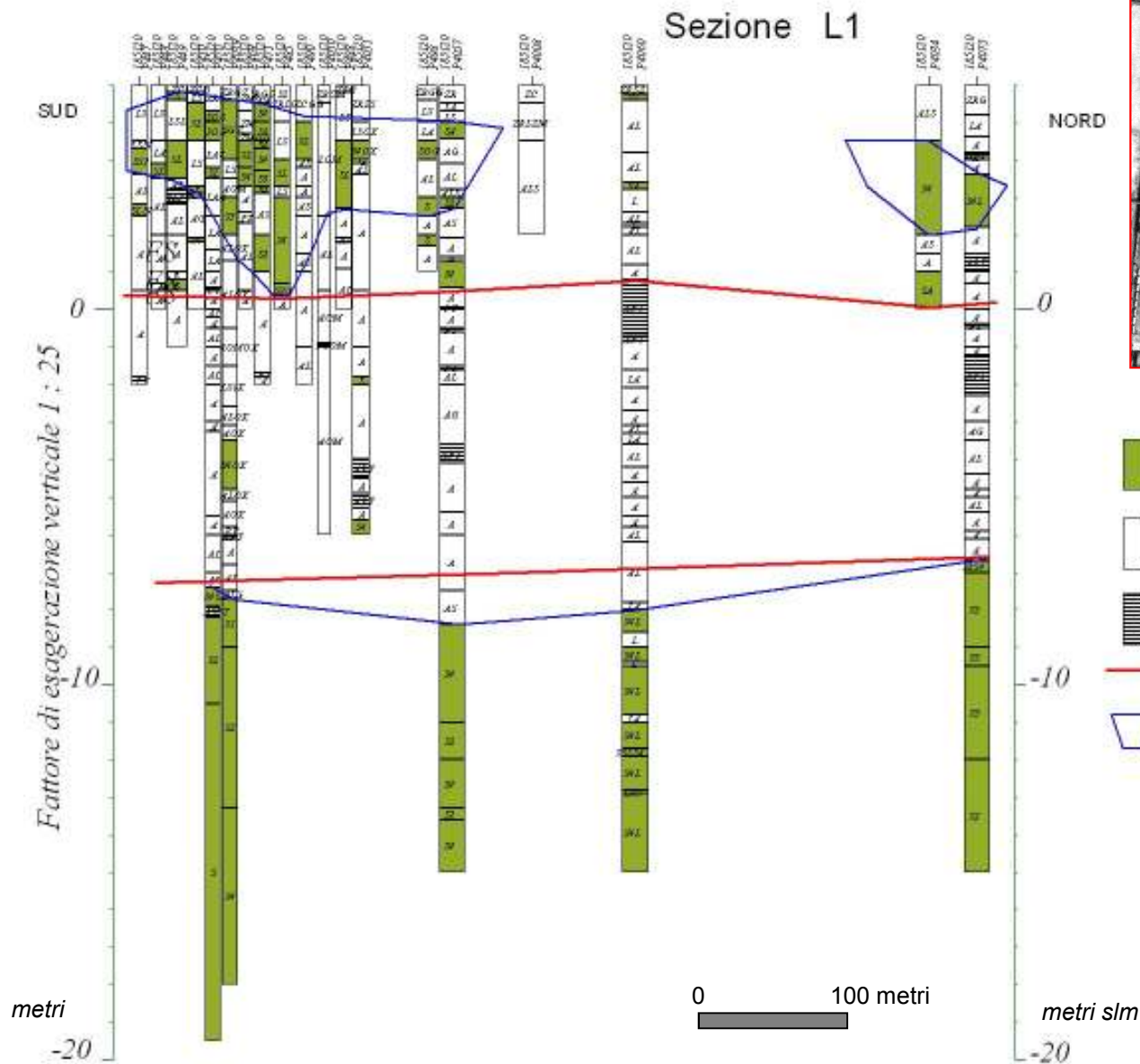
Acqua “vecchia” o acqua “nuova” ?







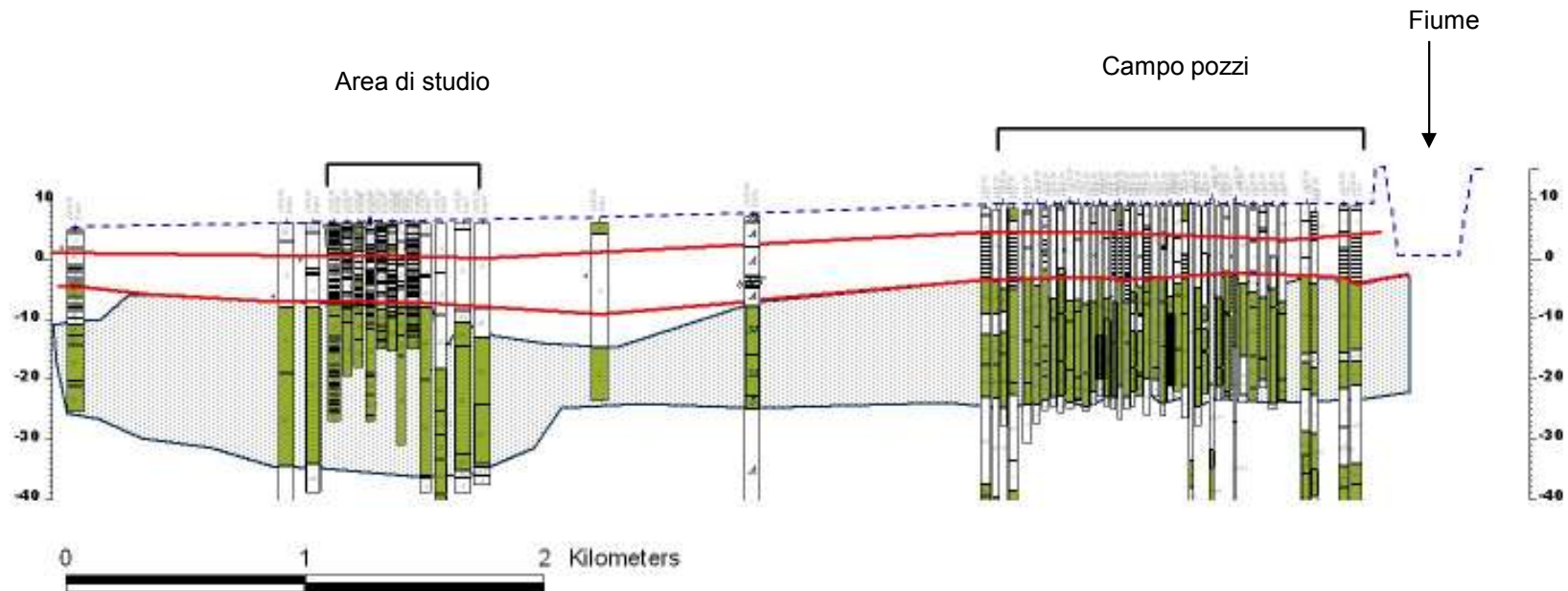
ZONA INDUSTRIALE
DI FERRARA NORD









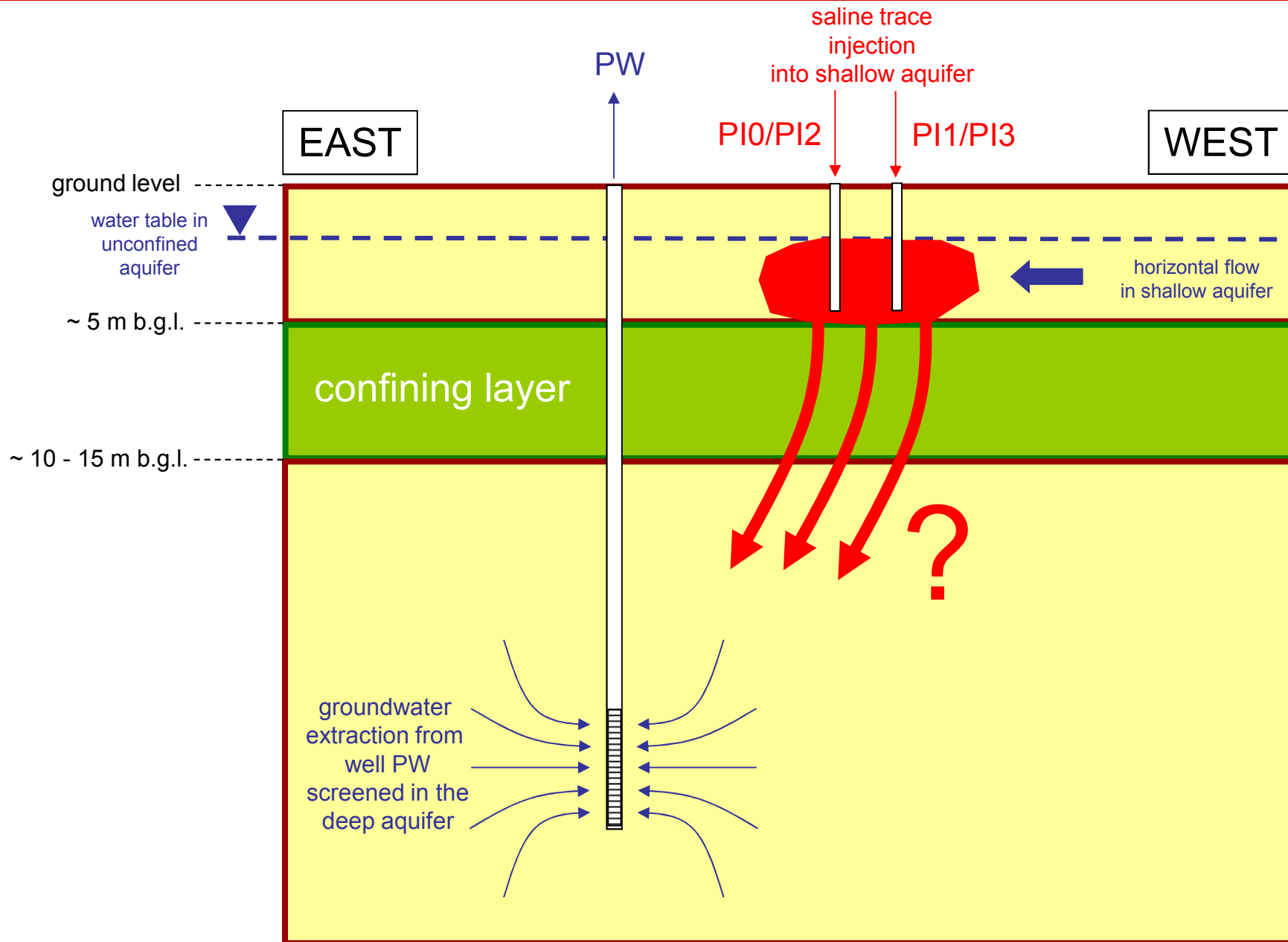
- sabbie
- limi, argille
- limi, argille con sostanza org.
- limiti tra unità stratigrafiche e idrogeologiche
- limiti dei corpi sabbiosi



Estensione regionale delle formazioni di interesse



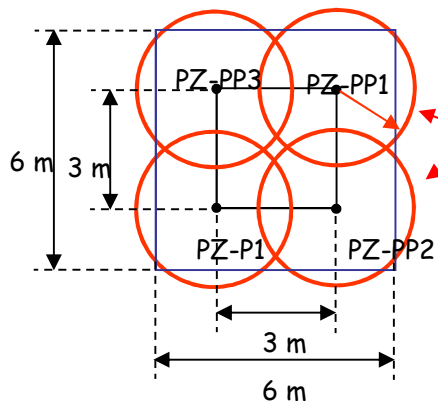
-  Sabbie
-  Limi e argille
-  Limi e argille con sostanza organica
-  **Limite tra le unità geologiche**
-  Limite dei corpi sabbiosi
-  Profilo topografico





Test con tracciante

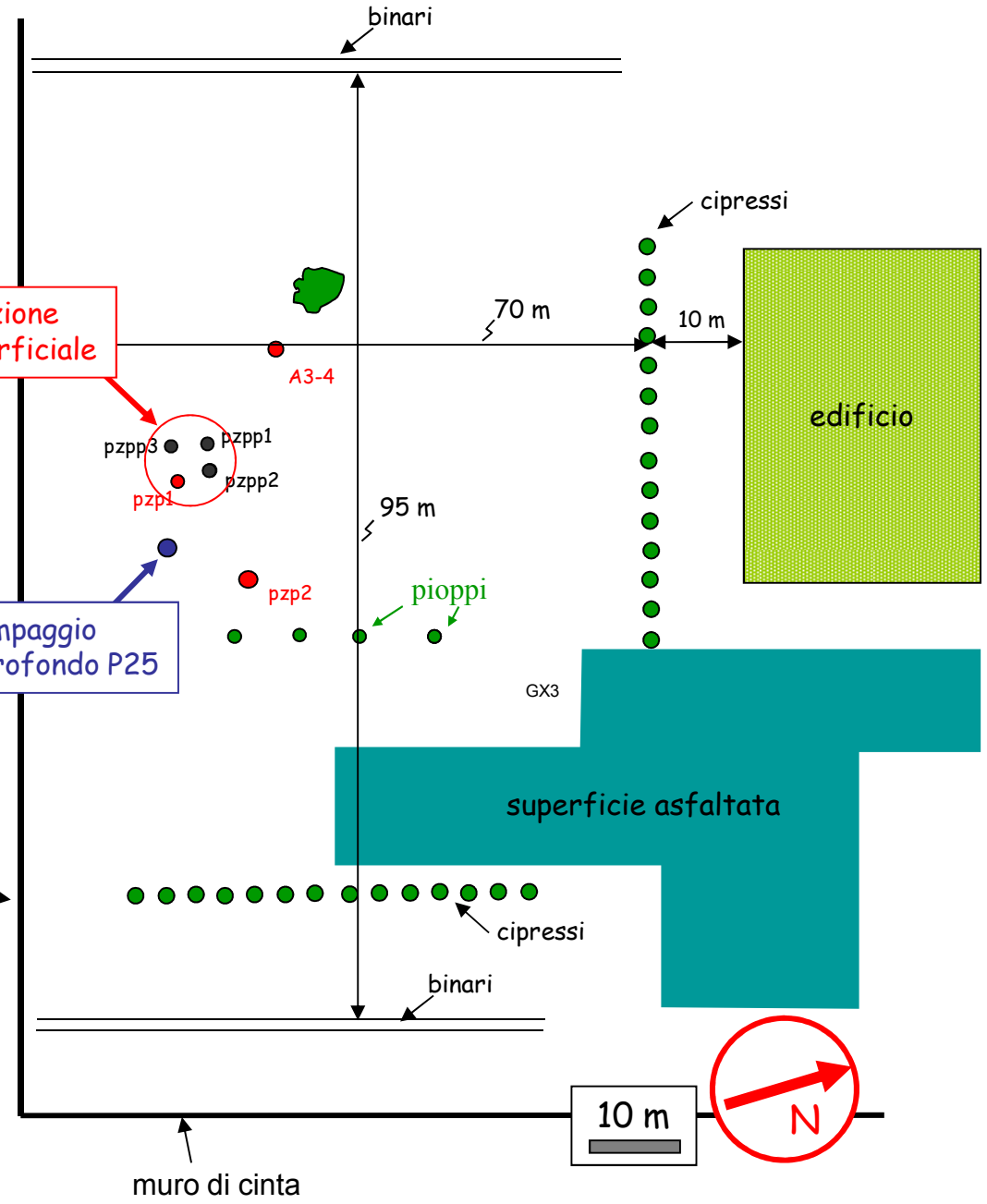
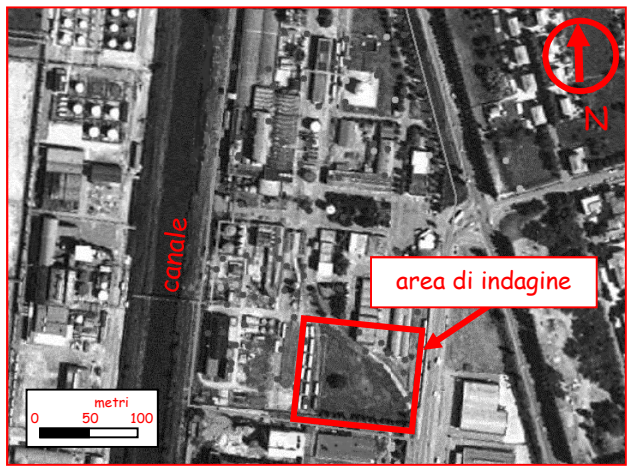
volume d'acqua iniettato = 20 m³
concentrazione NaCl = 6 g/litro
conduttività della soluzione ≈ 11 mS/cm
conduttività dell'acqua in sito ≈ 1-2 mS/cm
durata dell'iniezione ≈ 22 ore



pozzetti di iniezione nell'acquifero superficiale

raggio di iniezione di ciascun pozzo

pozzo di pompaggio dall'acquifero profondo P25





pozzetti di iniezione

pozzo P25



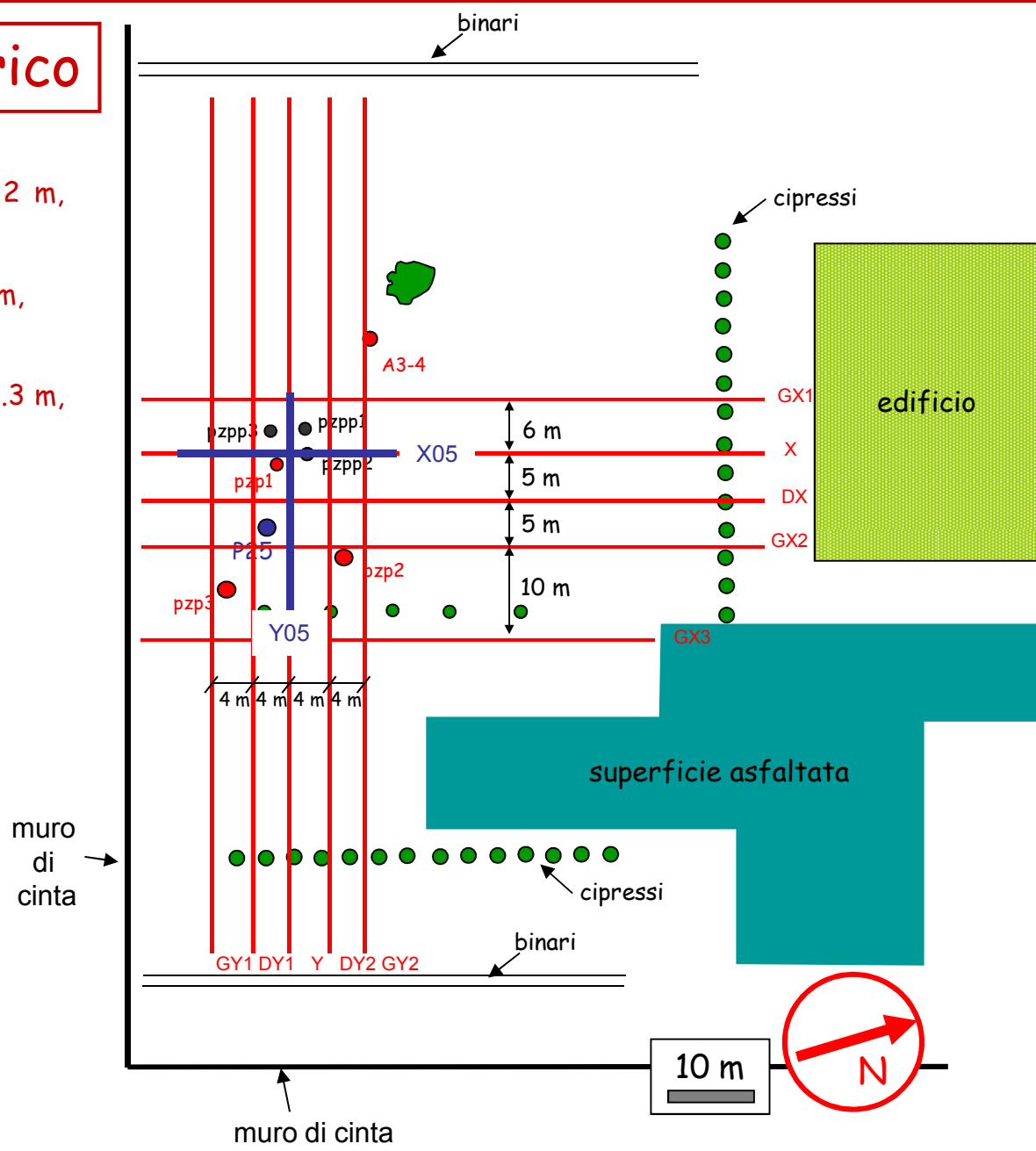
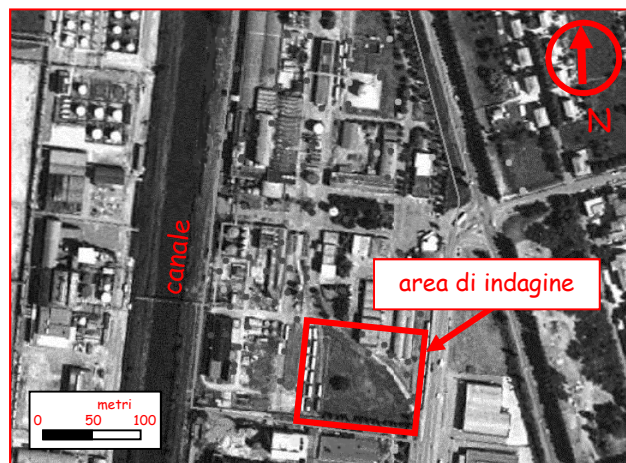
Monitoraggio geoelettrico

5 linee a 48 elettrodi E-W (Y) a spaziatura 2 m, lunghezza totale 94 m

4 linee a 48 elettrodi N-S (X) a spaziatura 1.5 m, lunghezza totale 70.5 m

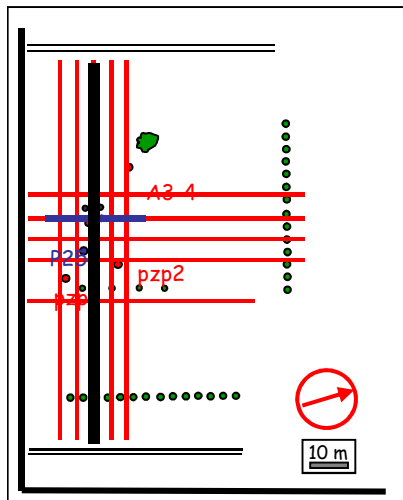
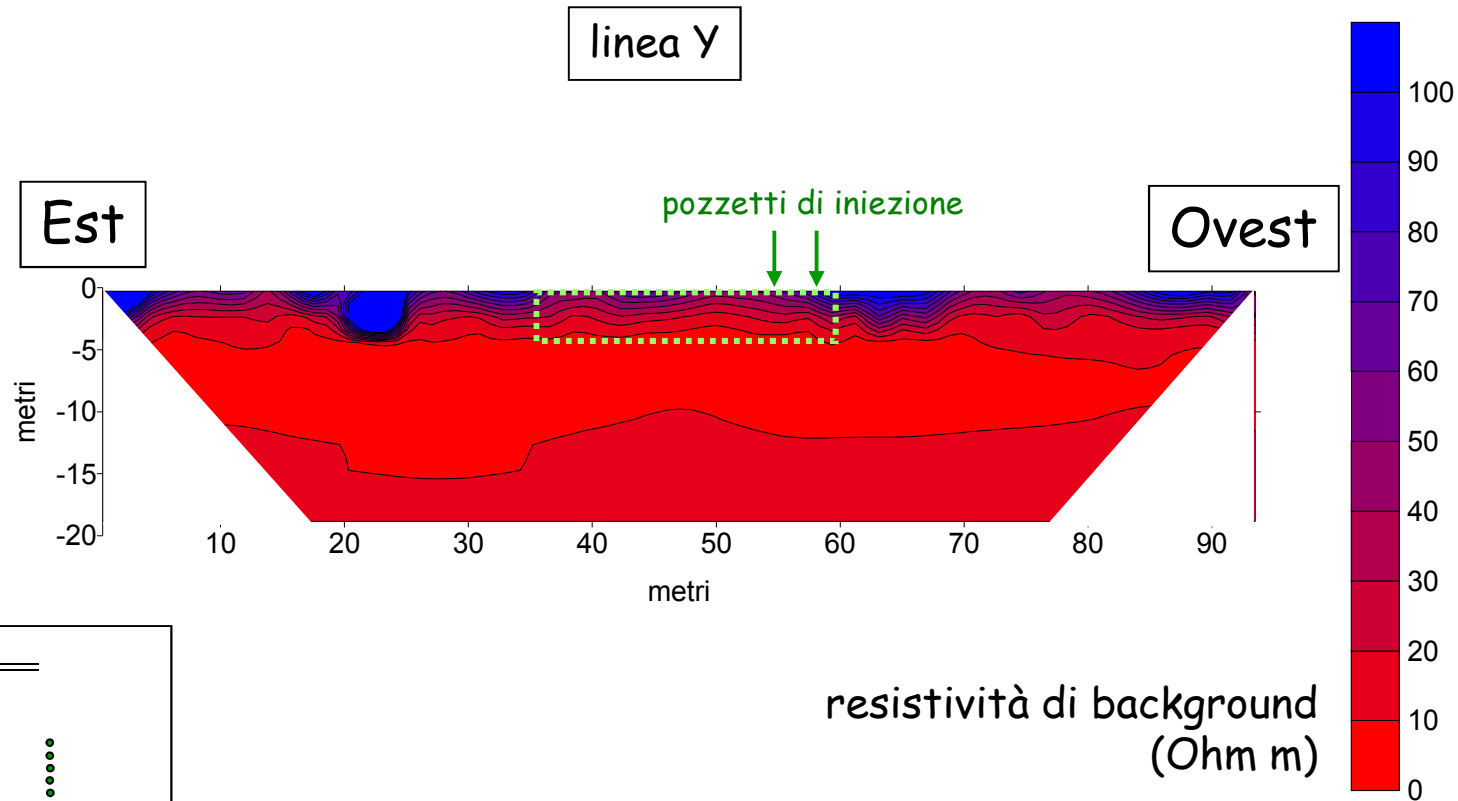
1 linee a 48 elettrodi N-S (GX3) a spaziatura 1.3 m, lunghezza totale 61.1 m

2 linee a 48 elettrodi ad alta risoluzione (X05 ed Y05) a spaziatura 0.5 m, lunghezza totale 23.5 m



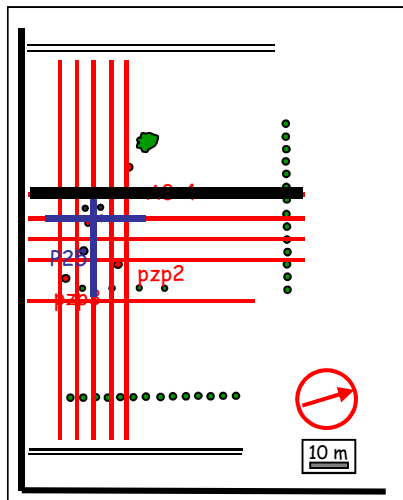
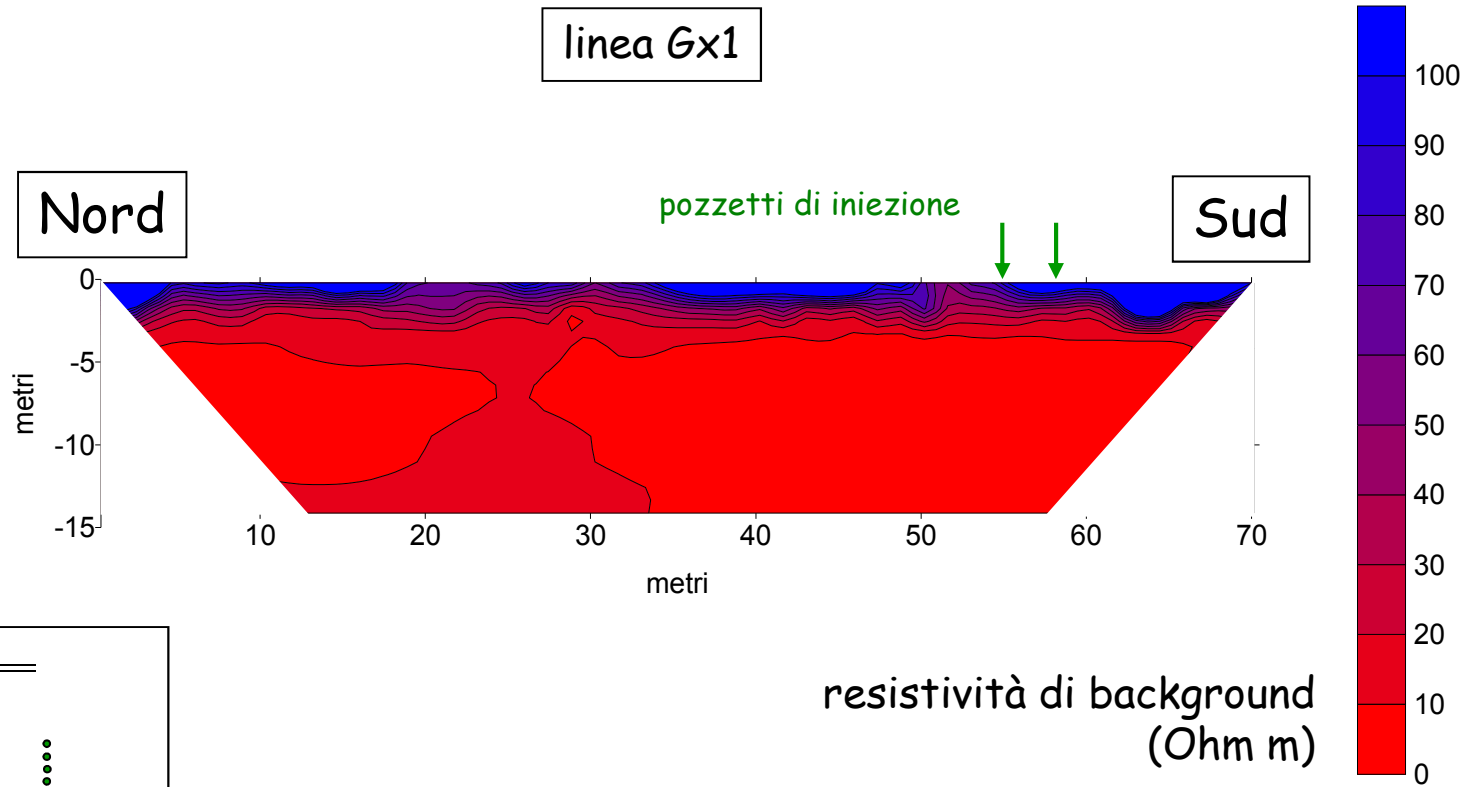


Survey di base (pre-iniezione)



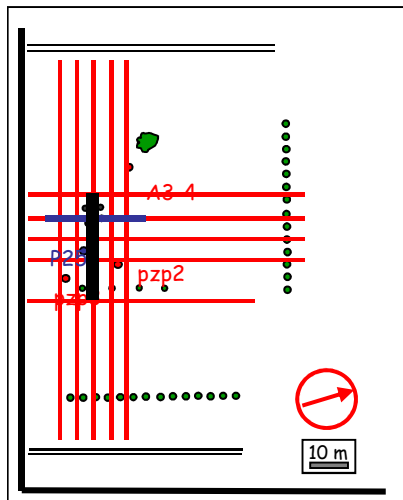
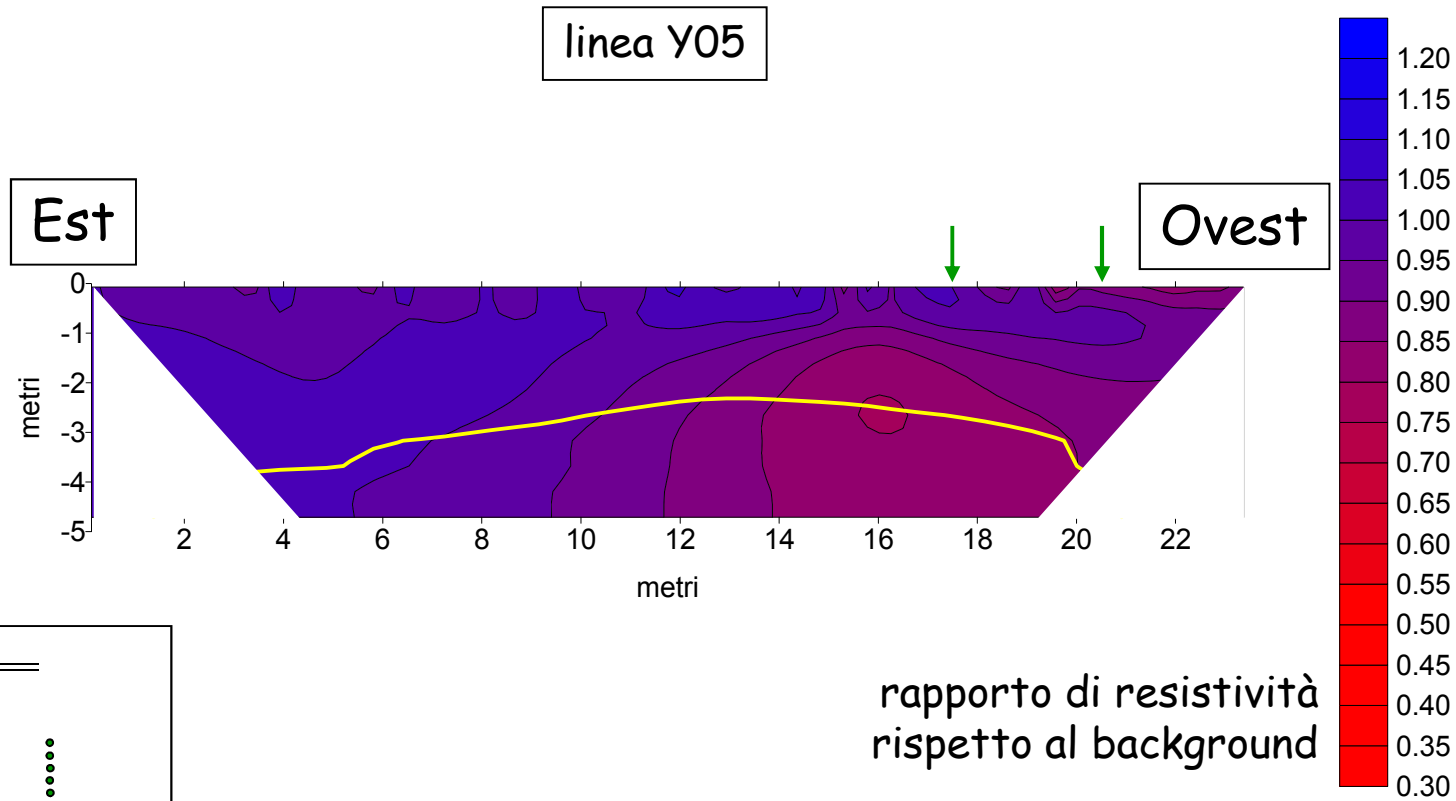


Survey di base (pre-iniezione)



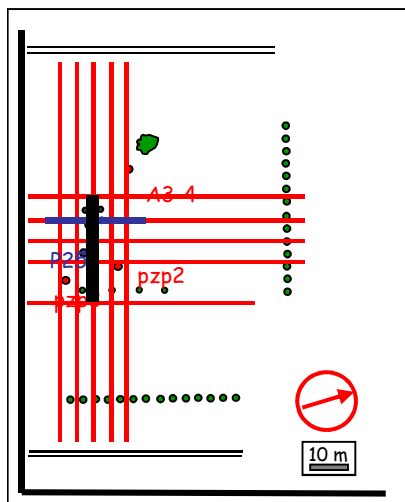
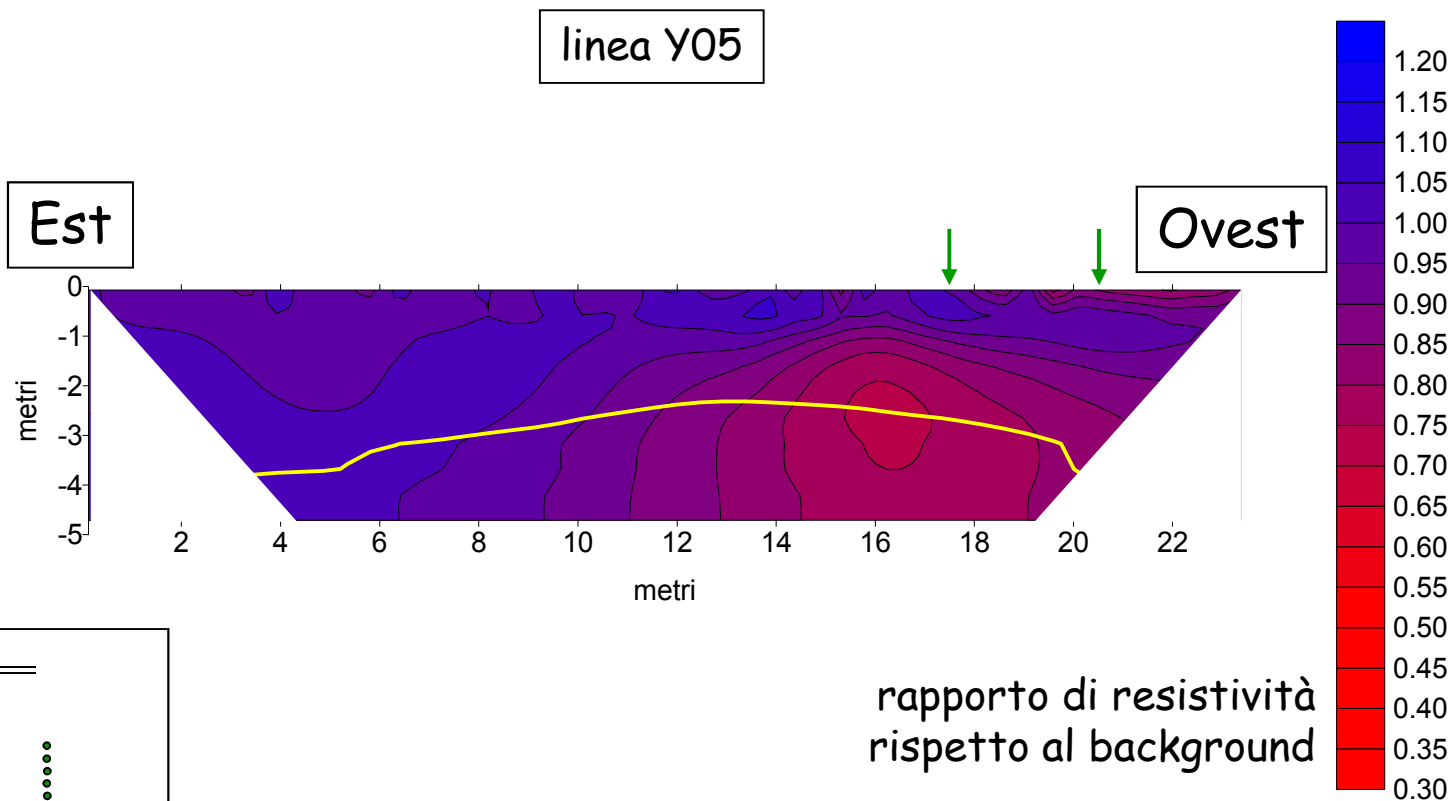


Iniezione del tracciante



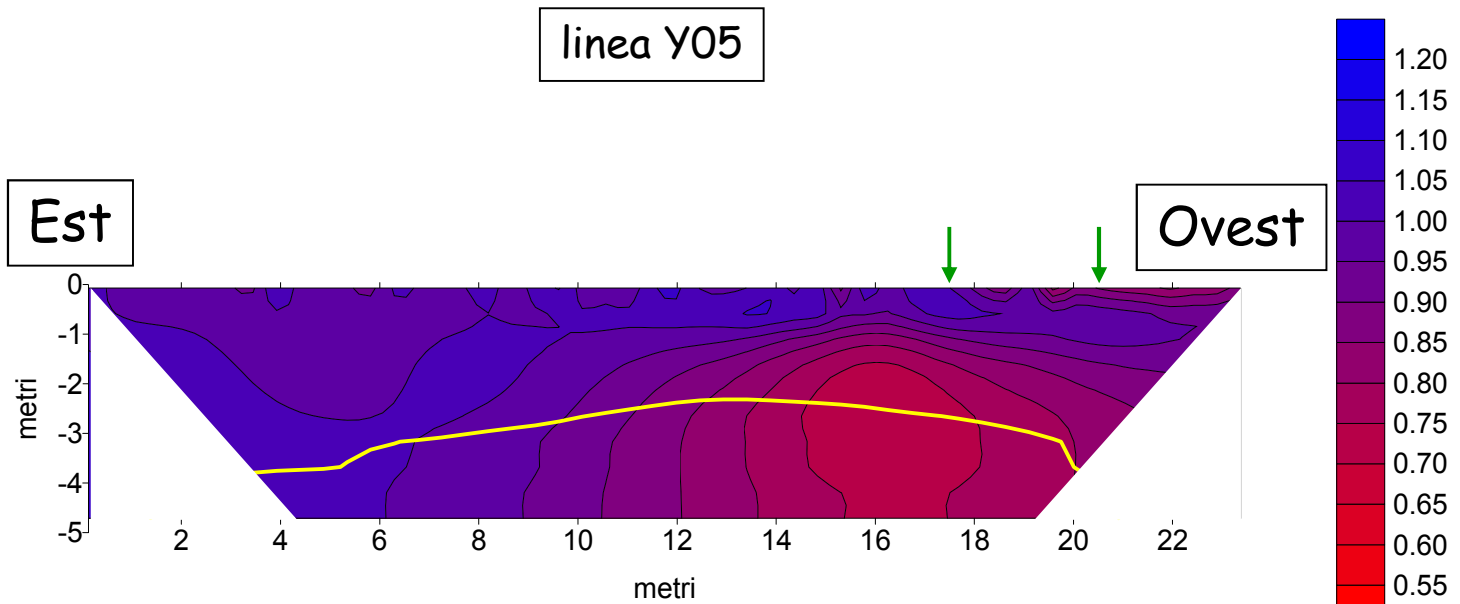


Iniezione del tracciante

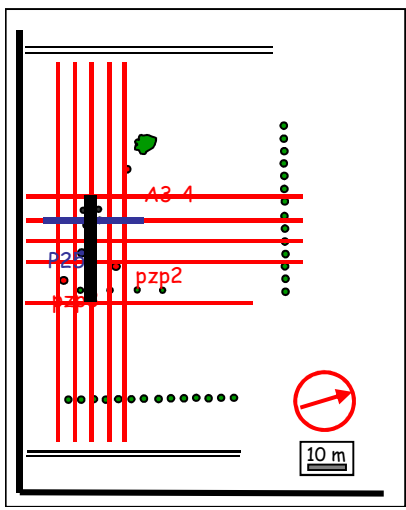
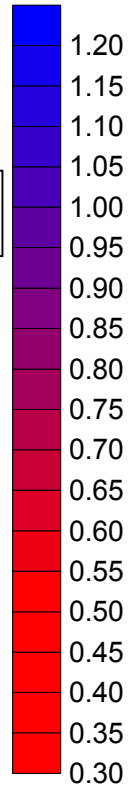




Iniezione del tracciante

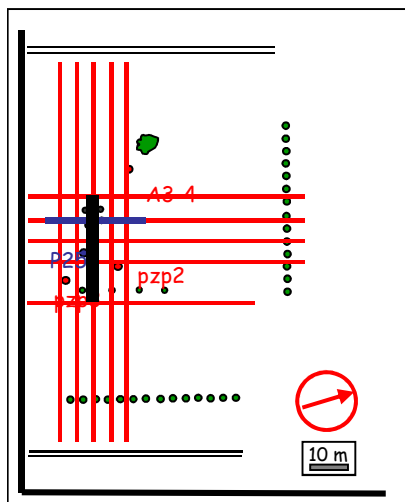
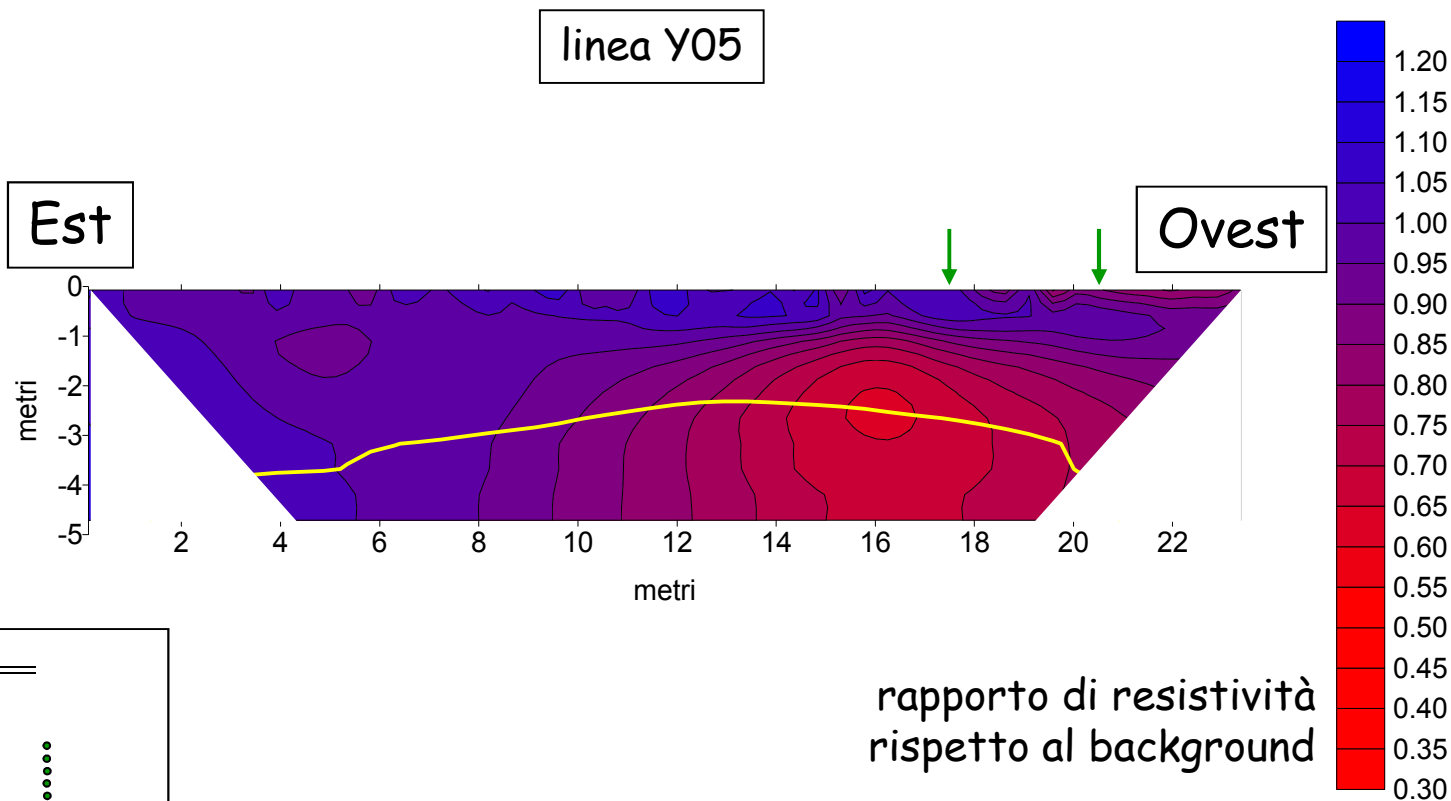


rapporto di resistività
rispetto al background



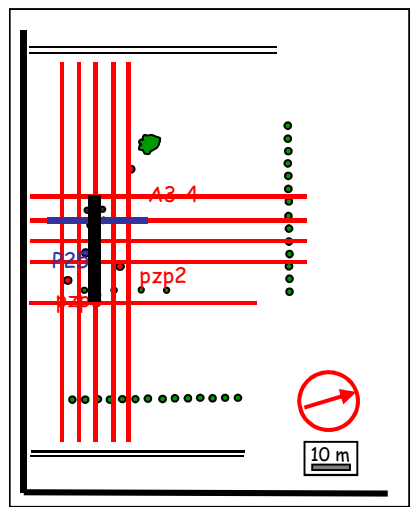
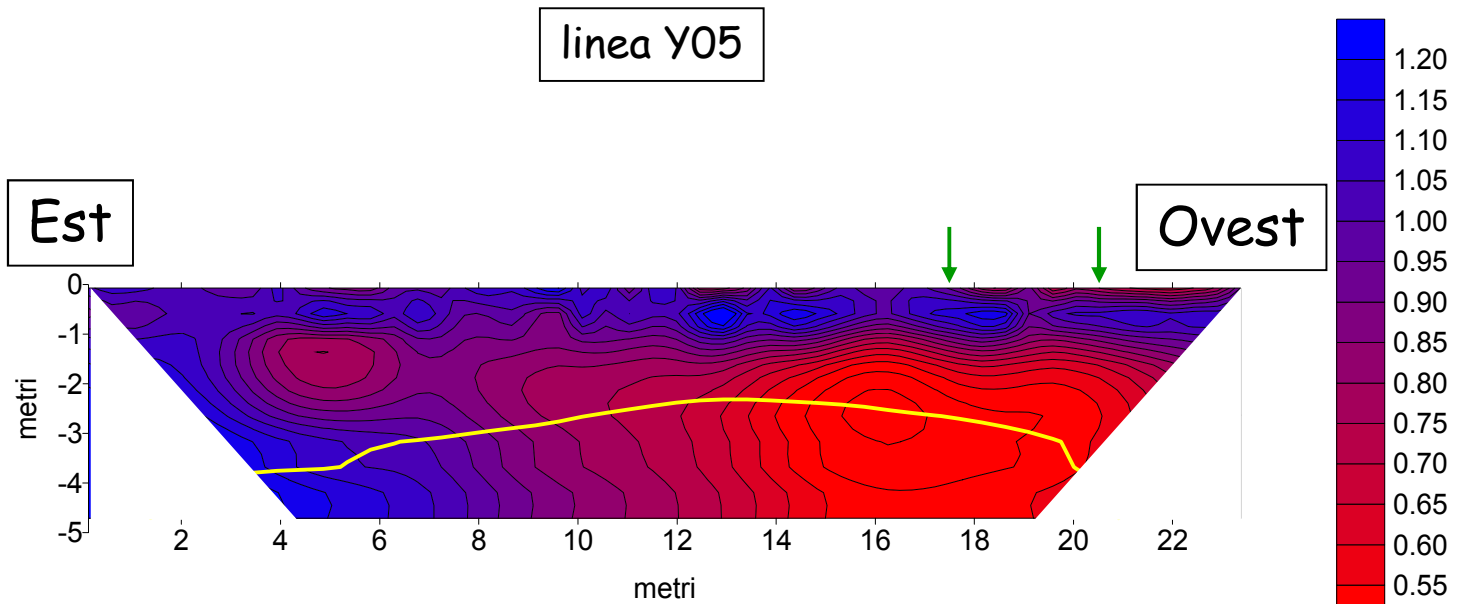


Iniezione del tracciante



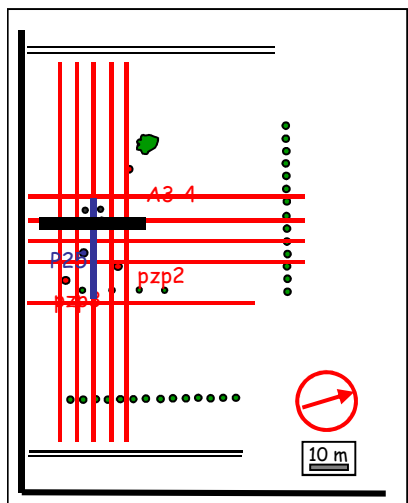
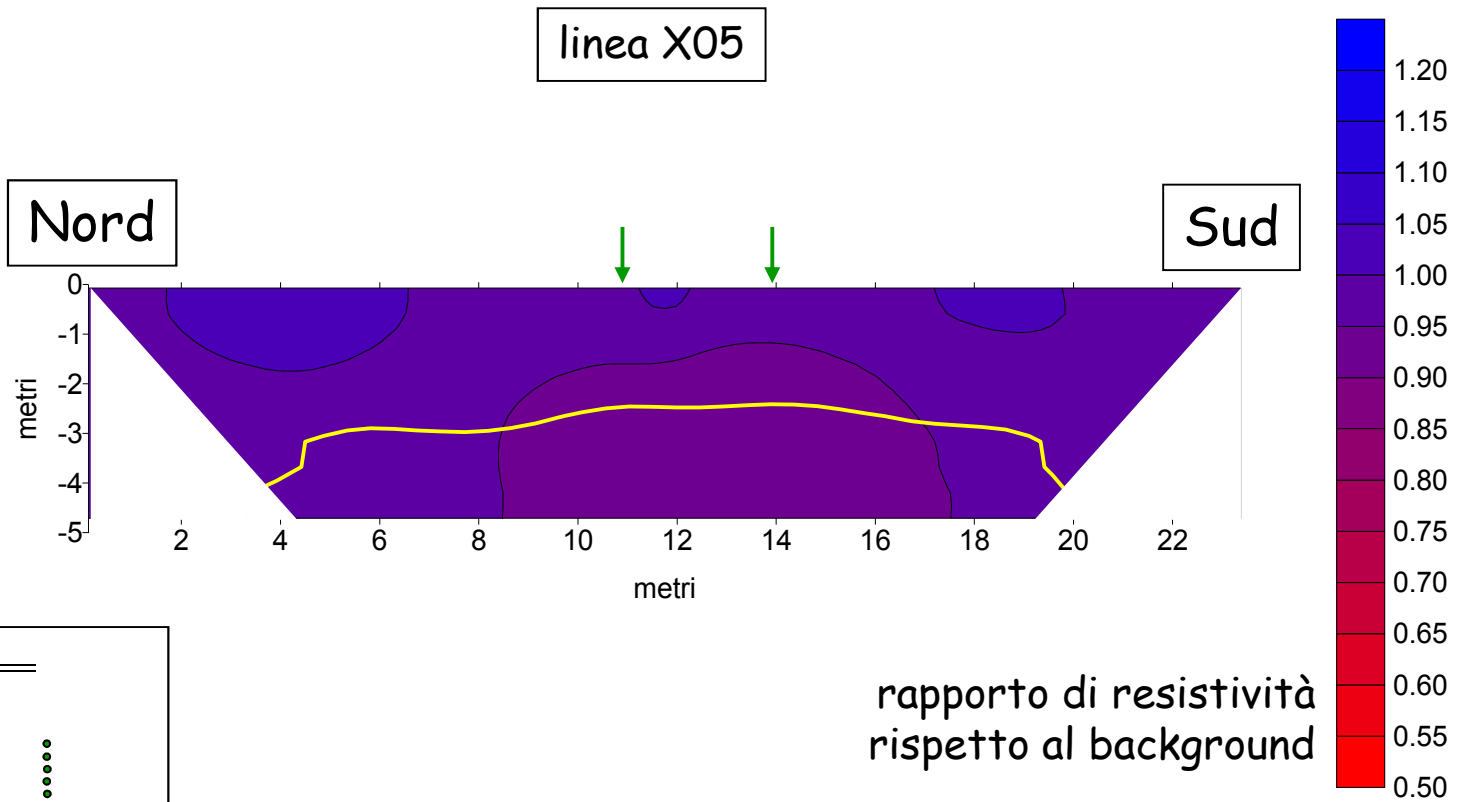


Iniezione del tracciante



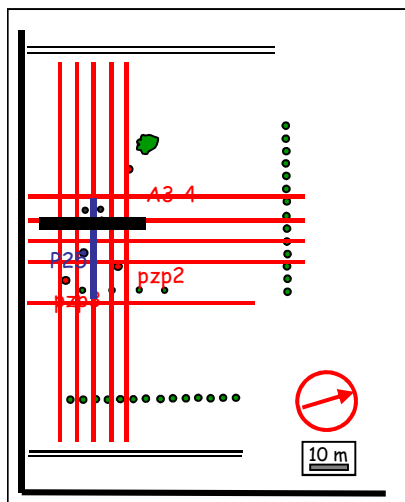
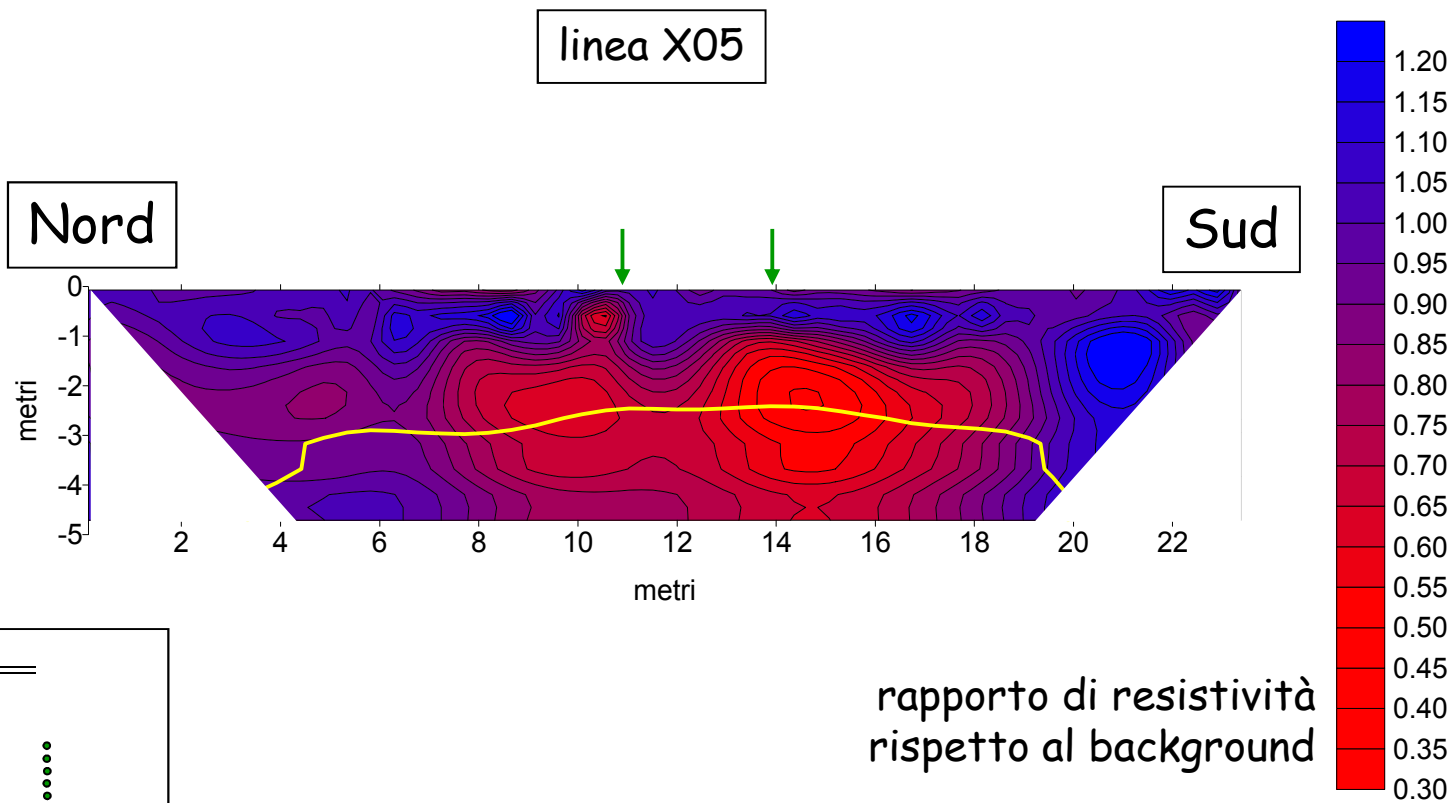


Iniezione del tracciante



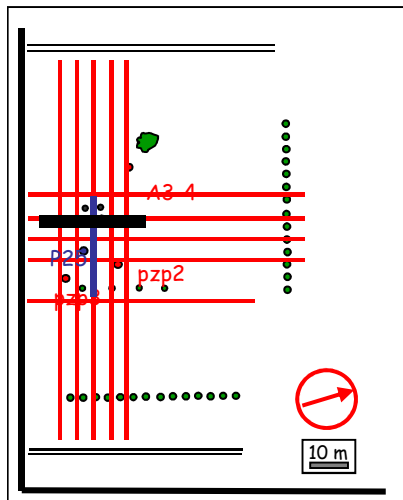
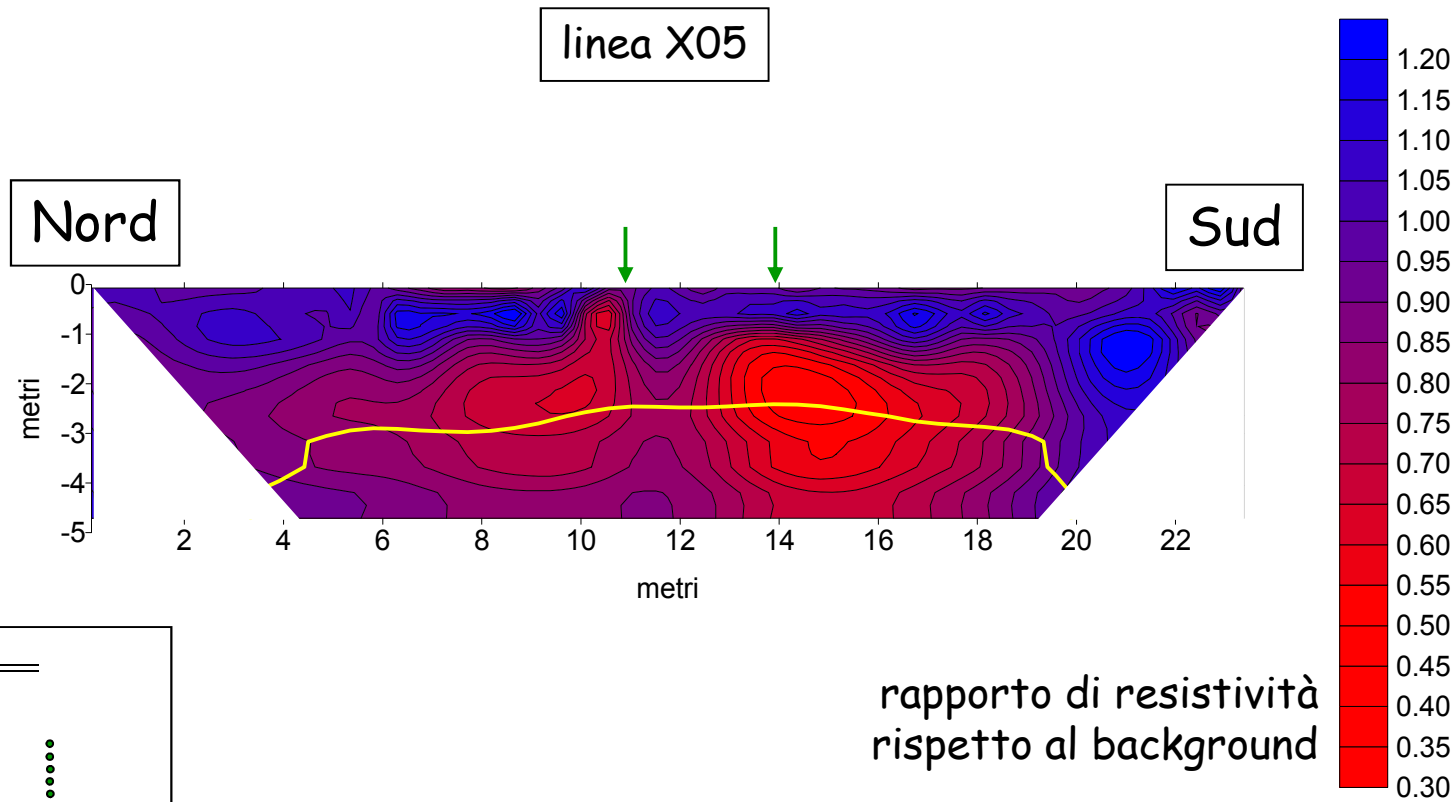


Iniezione del tracciante



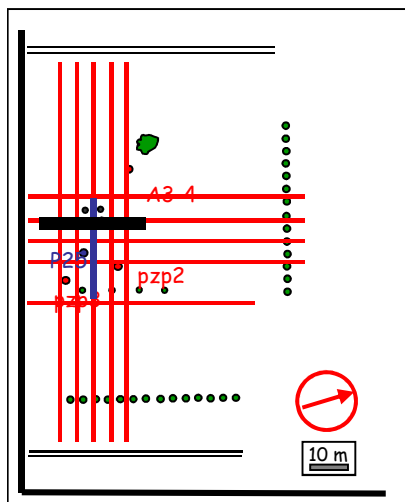
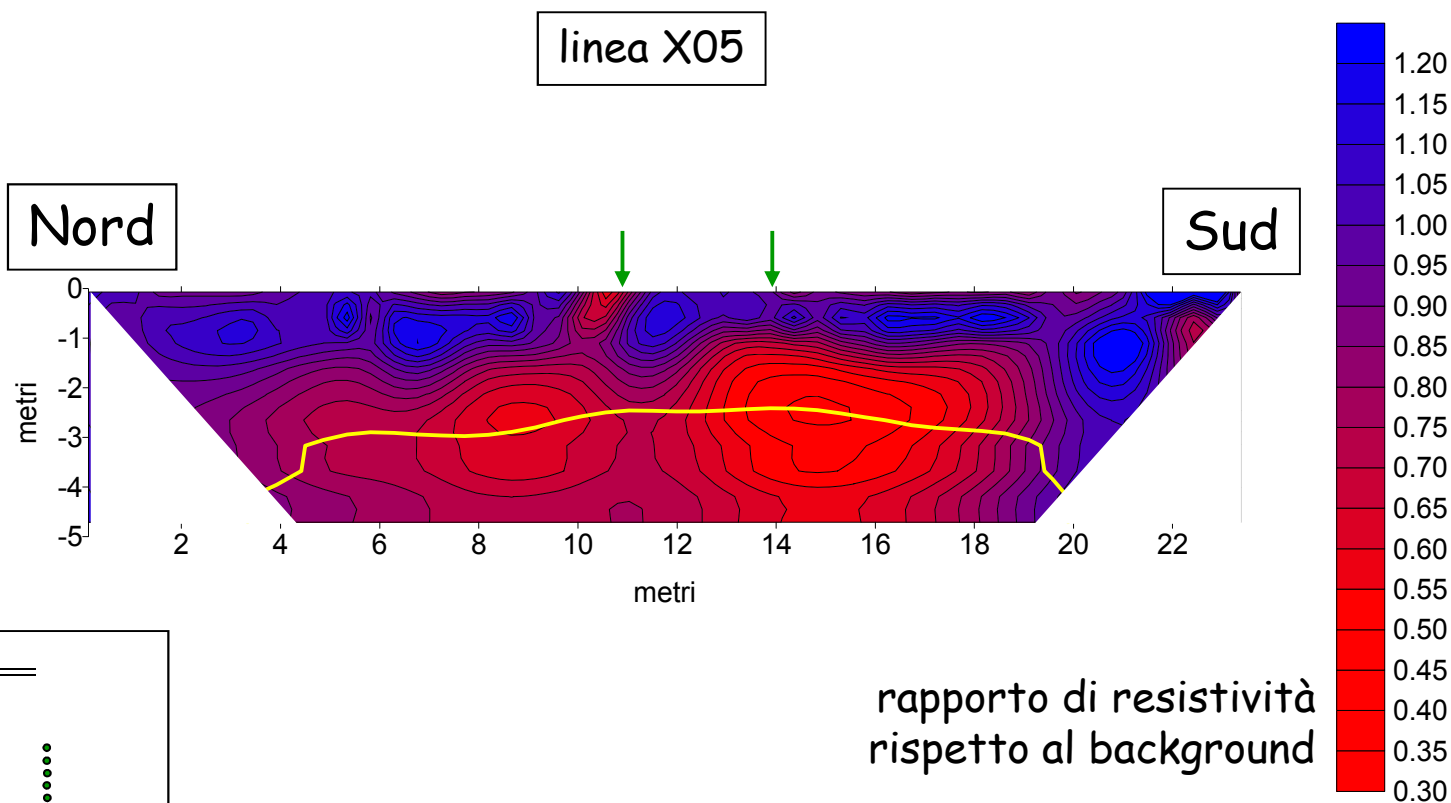


Iniezione del tracciante





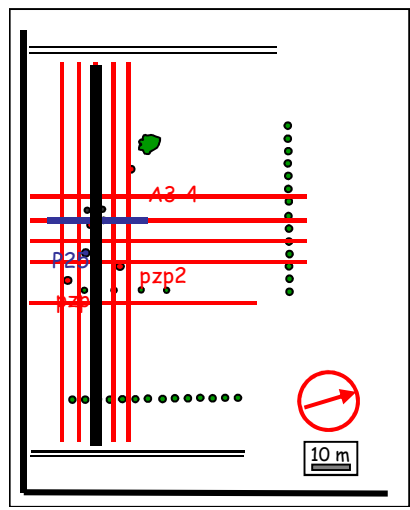
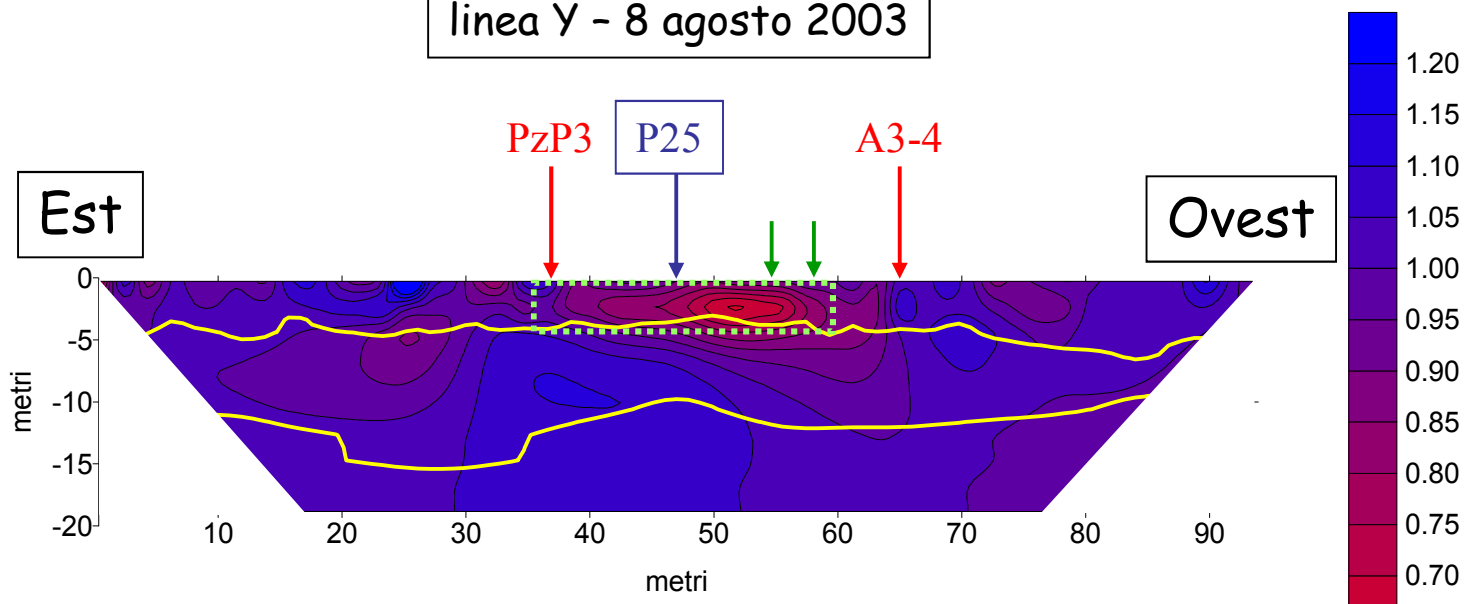
Iniezione del tracciante





Surveys post-iniezione

linea Y - 8 agosto 2003



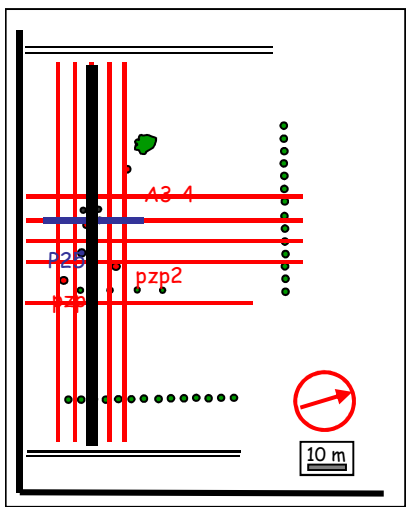
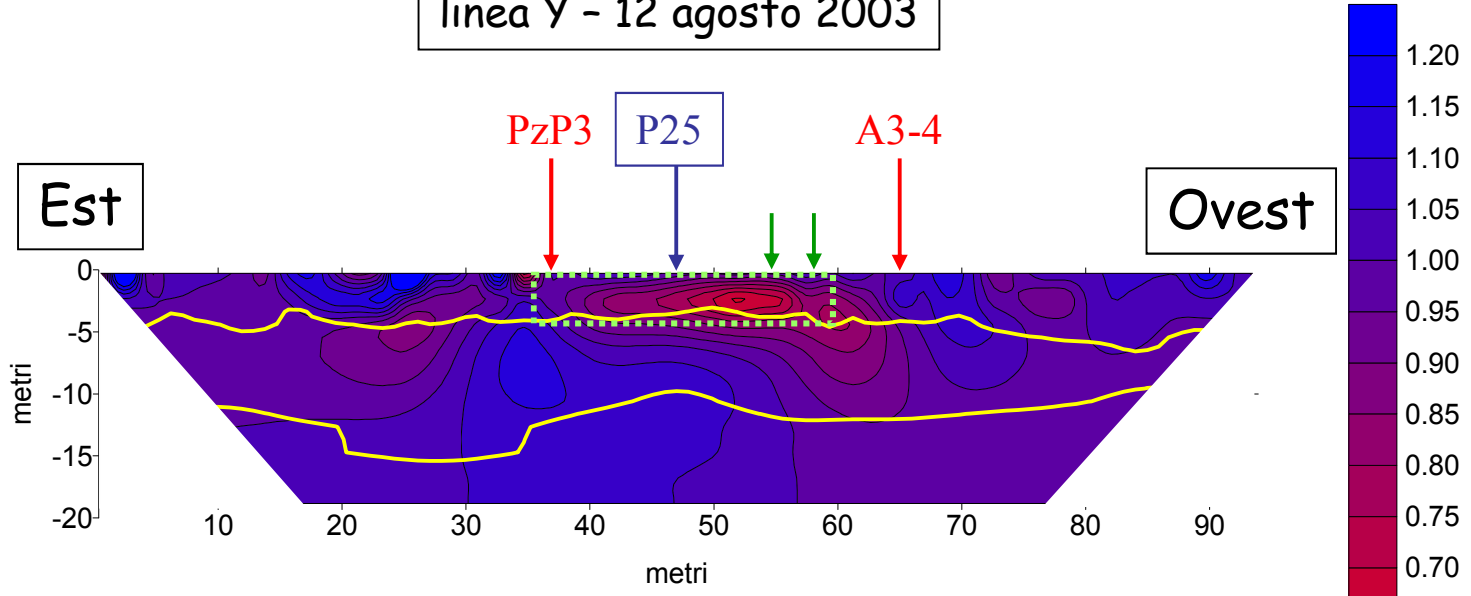
rapporto di resistività
rispetto al background

←
direzione prevalente della faldina superficiale



Surveys post-iniezione

linea Y - 12 agosto 2003



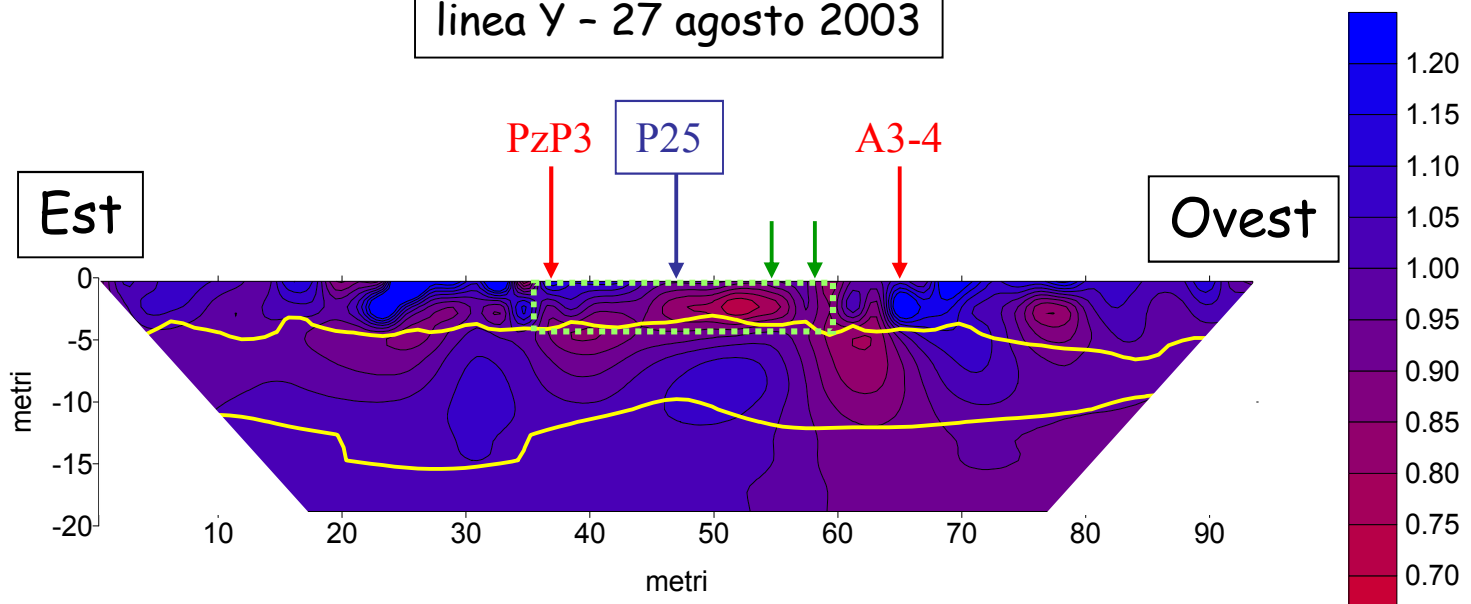
rapporto di resistività rispetto al background

←
direzione prevalente della faldina superficiale

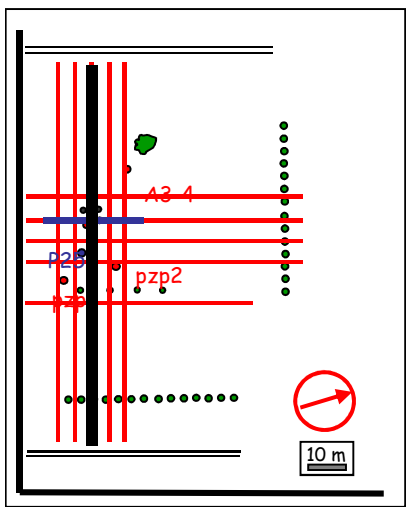


Surveys post-iniezione

linea Y - 27 agosto 2003



rapporto di resistività
rispetto al background

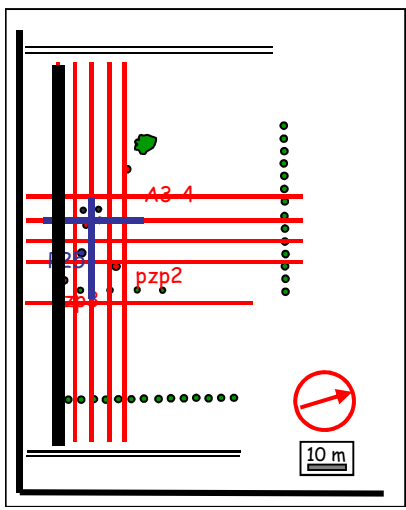
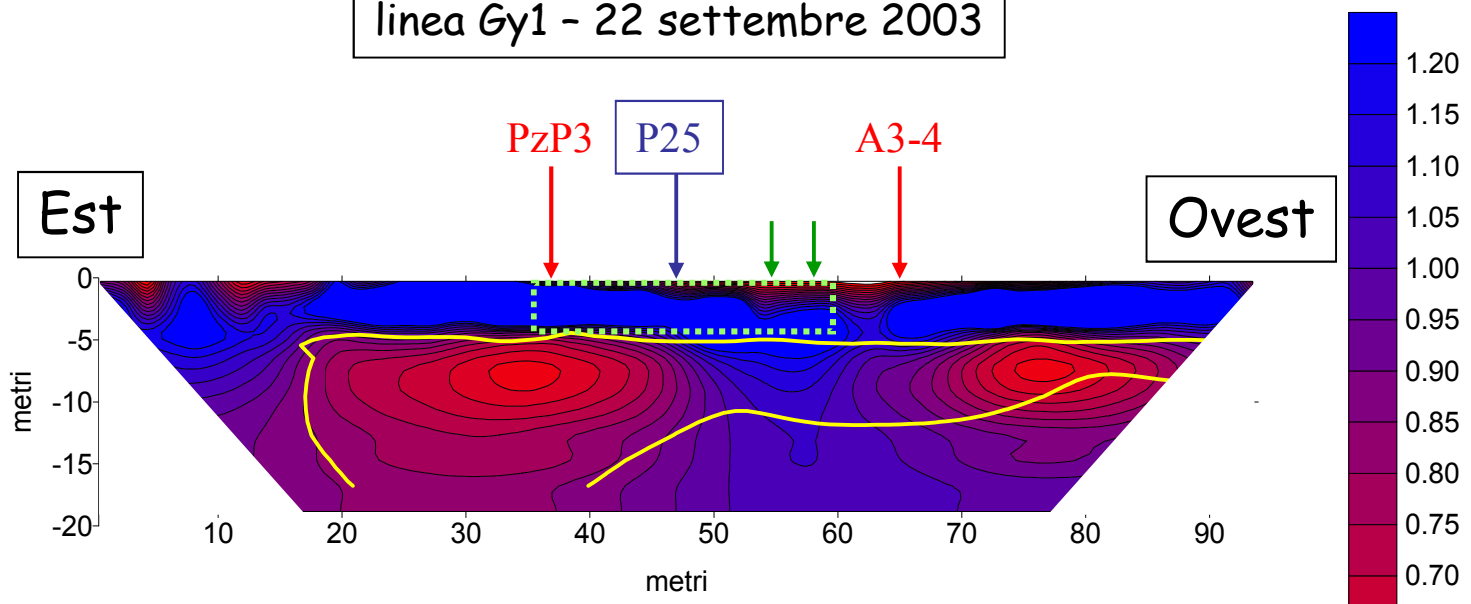


←
direzione prevalente della faldina superficiale



Surveys post-iniezione

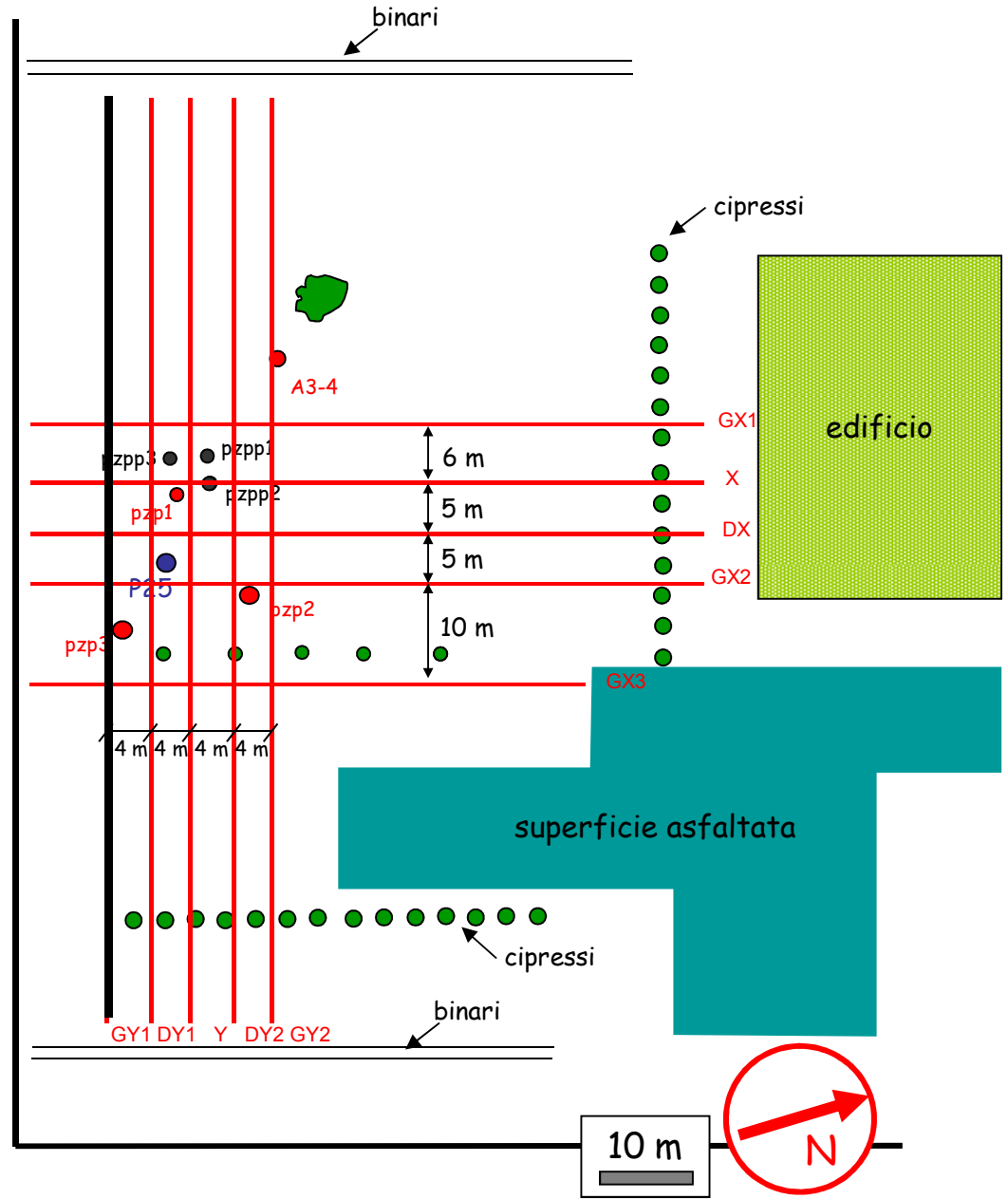
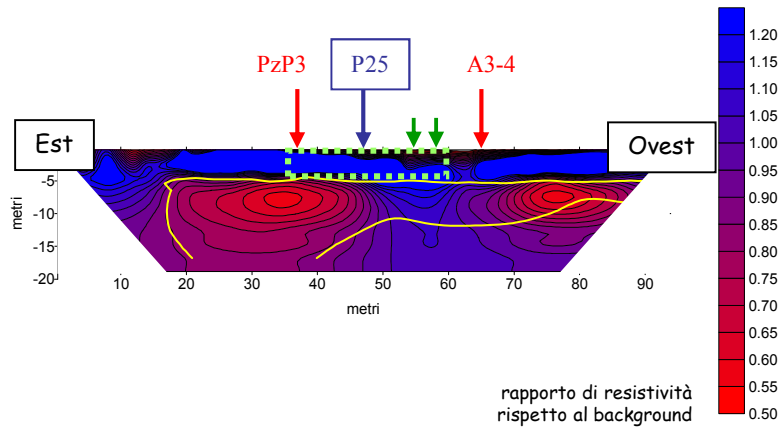
linea Gy1 - 22 settembre 2003





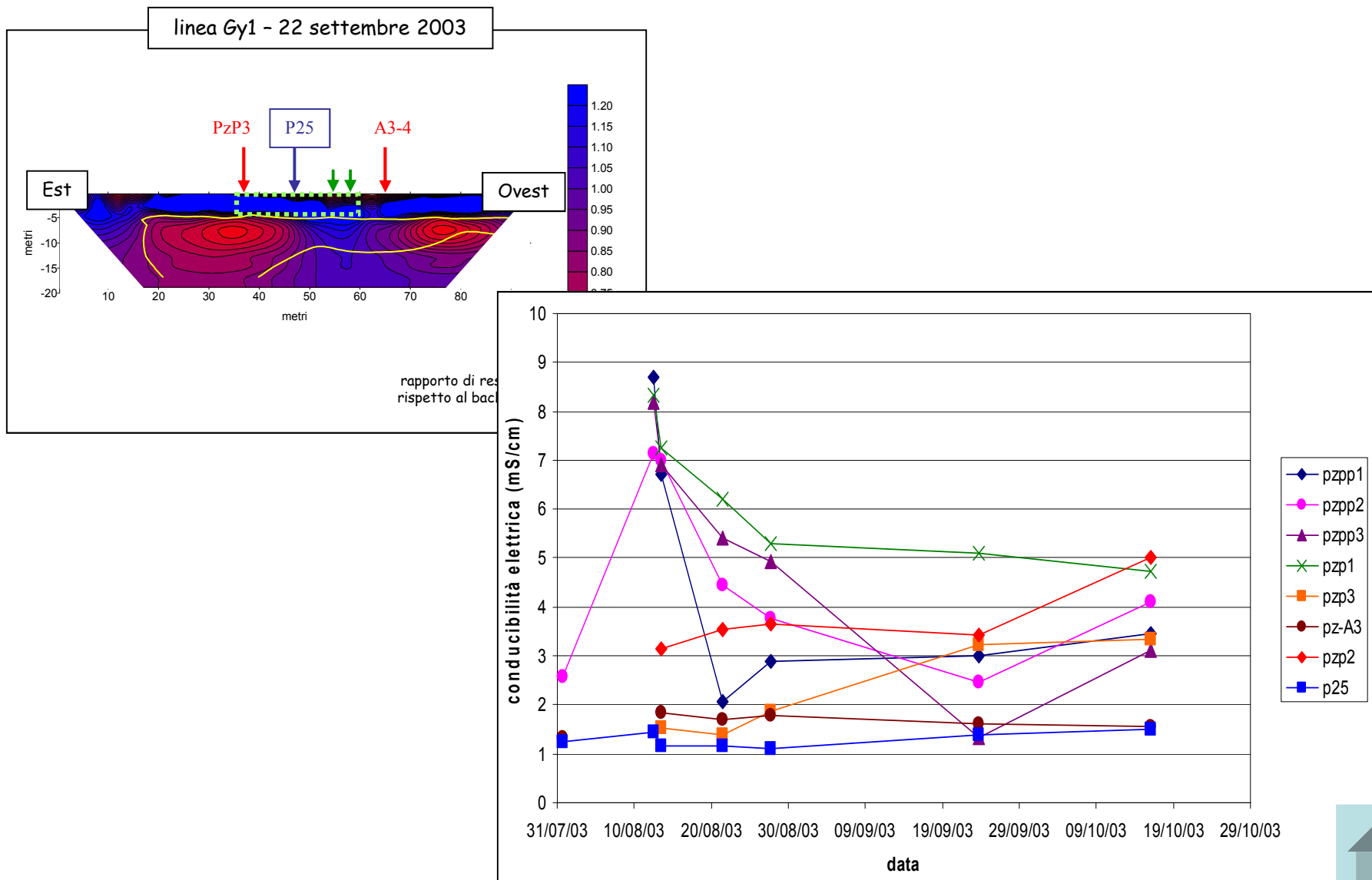
Surveys post-iniezione

linea Gy1 - 22 settembre 2003

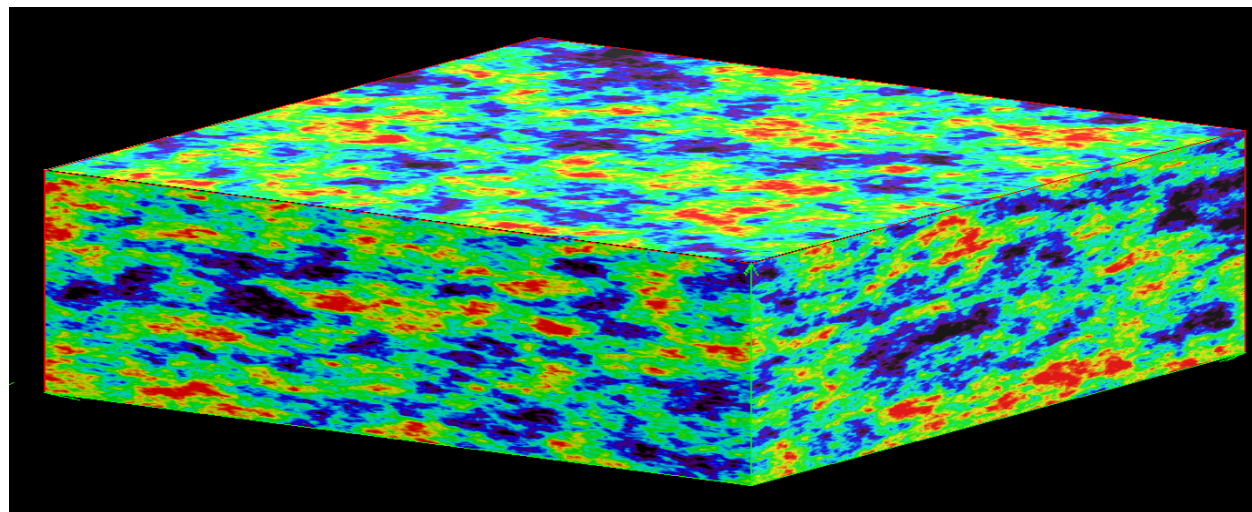
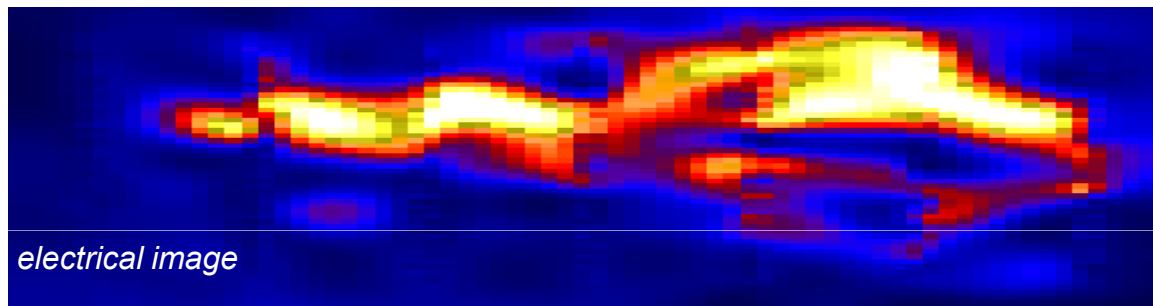
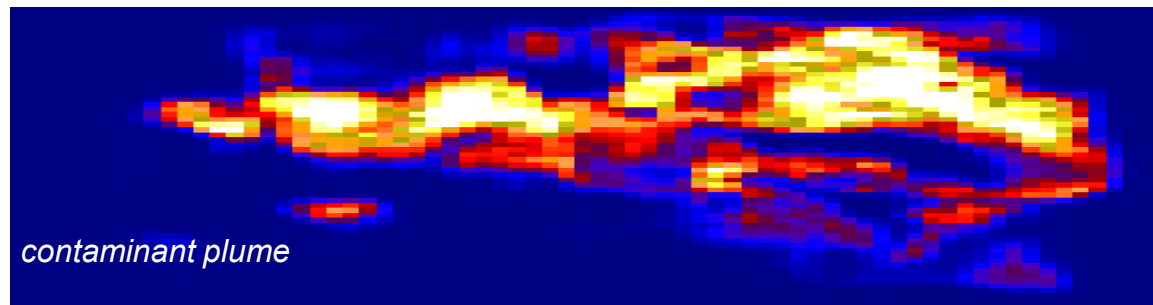




misure dirette di conducibilità elettrica







courtesy: A. Kemna – University of Bonn



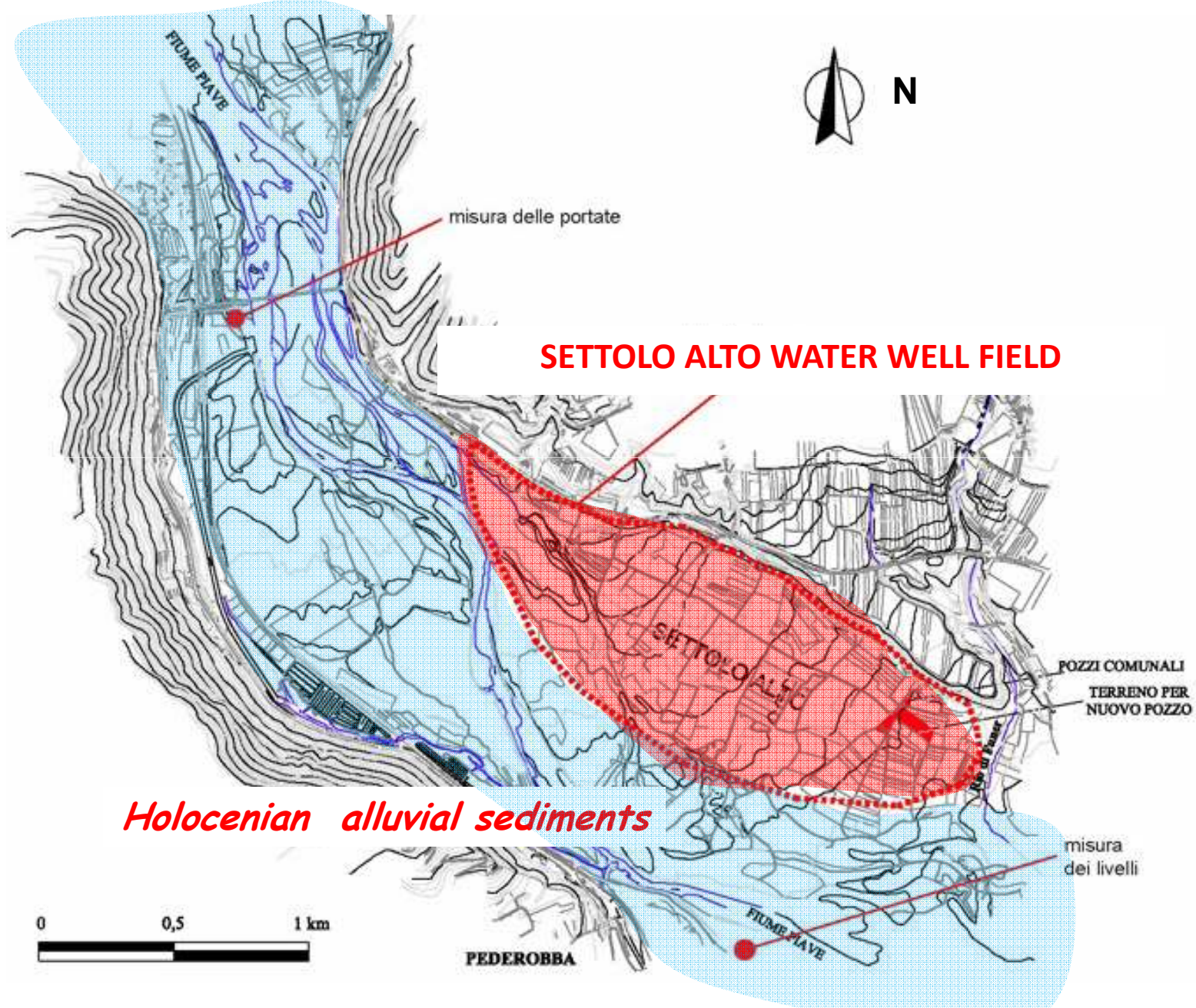
The *experimental* site of interest is placed in the water works well field of *Settolo Alto*.

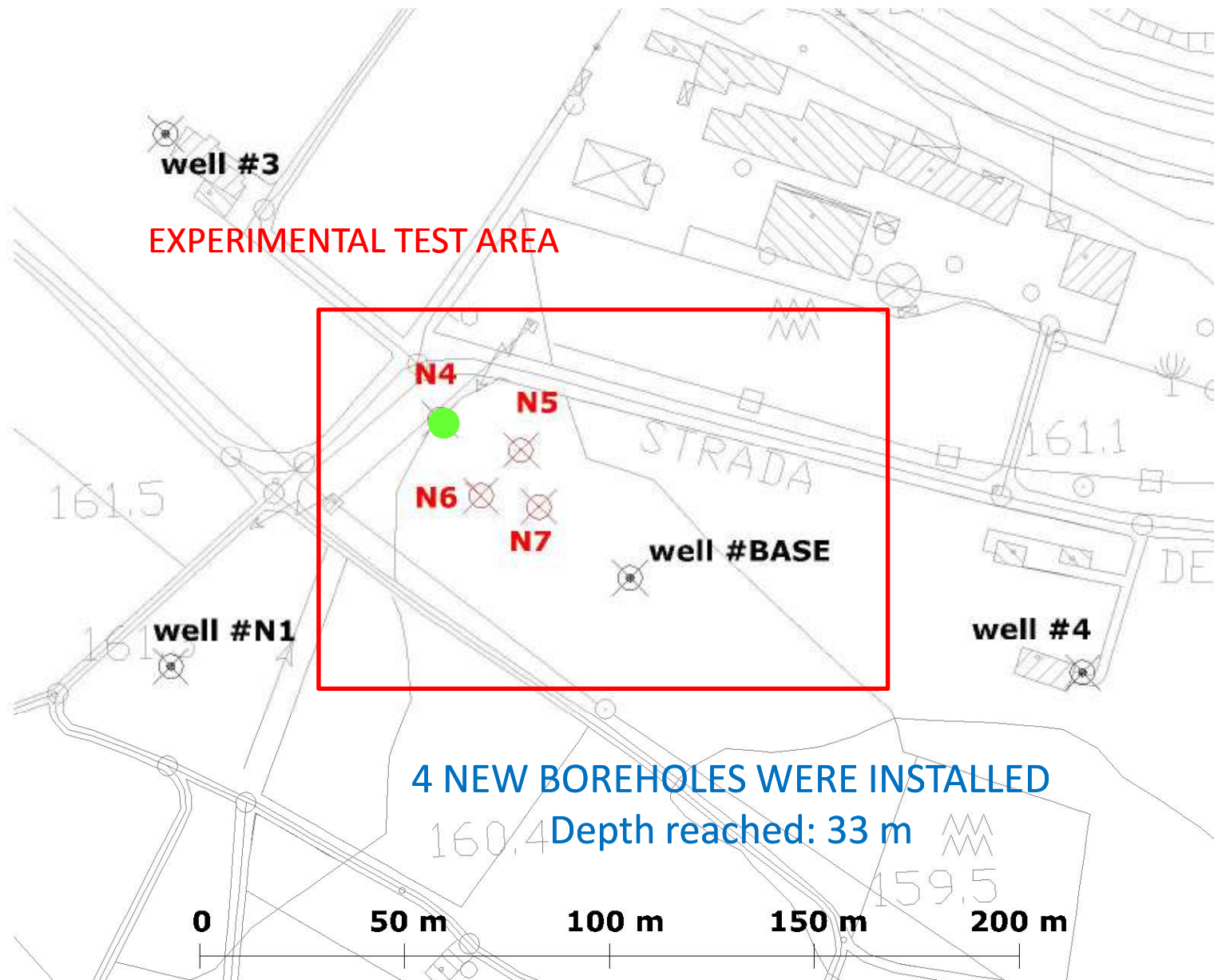
This is an area between the small town of *Valdobbiadene (Treviso - TV)* and the *Piave River (NE Italy)*.



“SETTOLO ALTO” WATER WELL FIELD

data information content: a field example

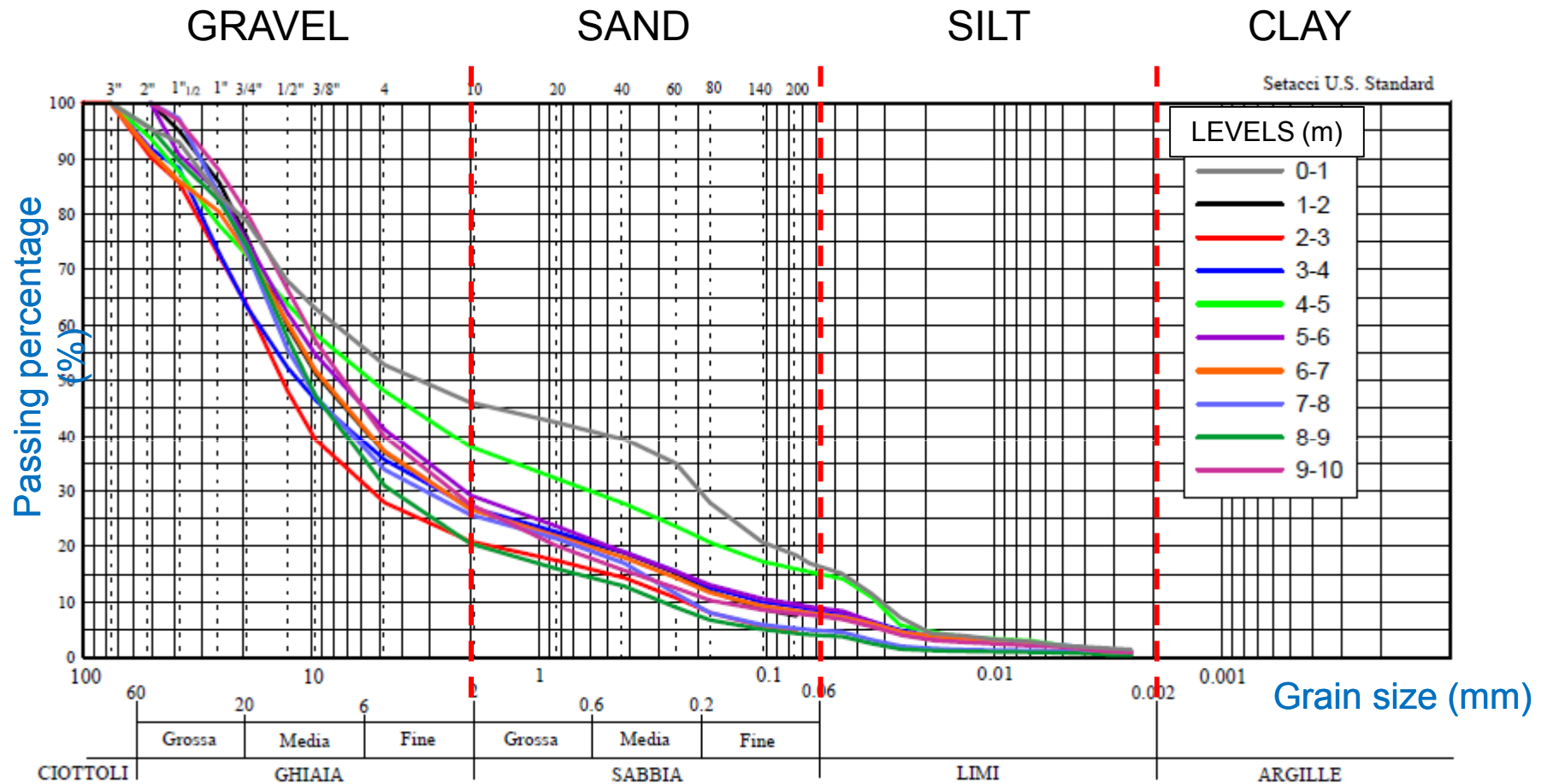




EXPERIMENTAL TEST AREA

4 NEW BOREHOLES WERE INSTALLED

Depth reached: 33 m

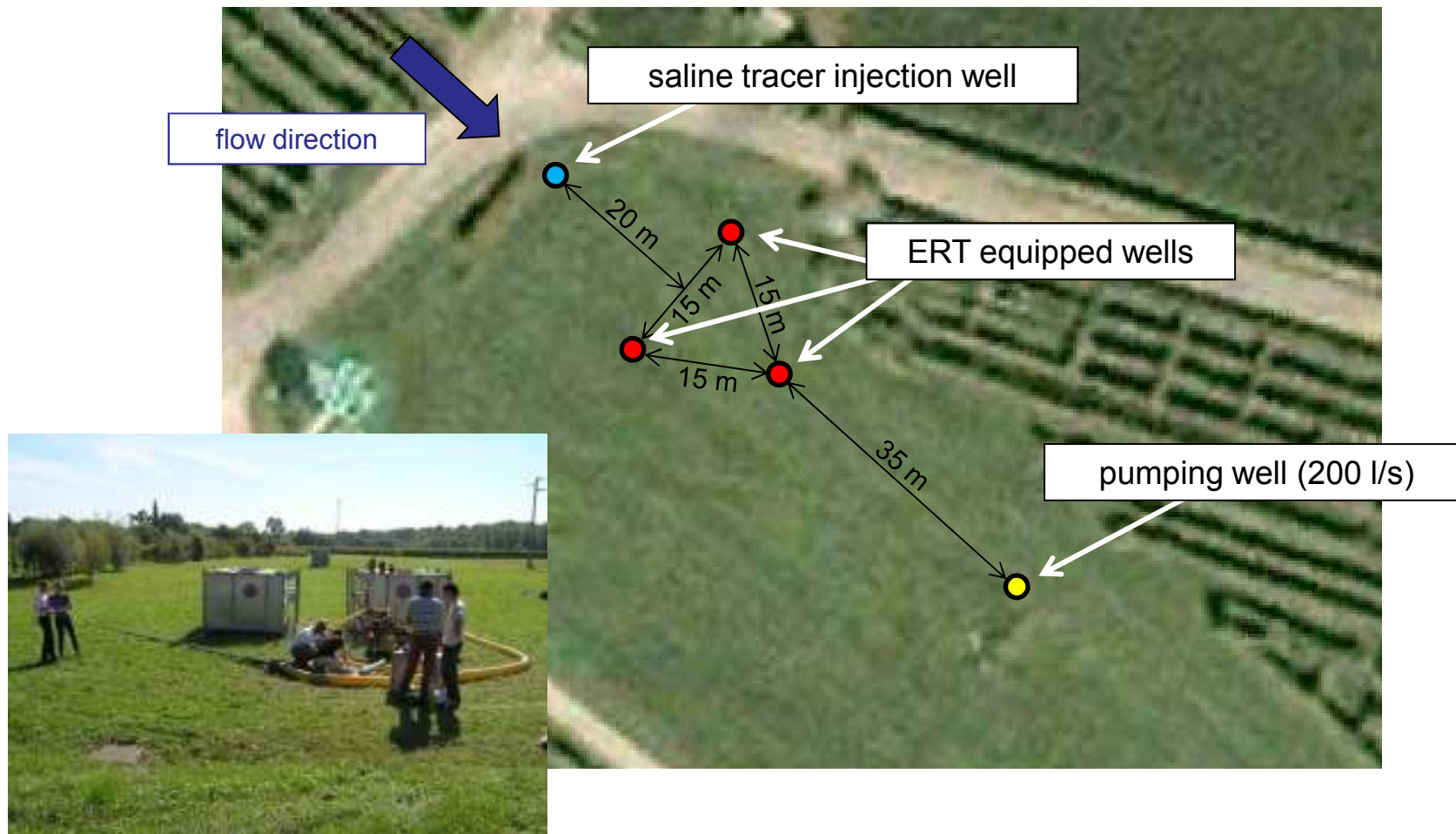


Grain size analysis: the curves clearly show the presence of **gravelly subsoil**



EXPERIMENTAL TEST AREA – Valdobbadiene – NE Italy

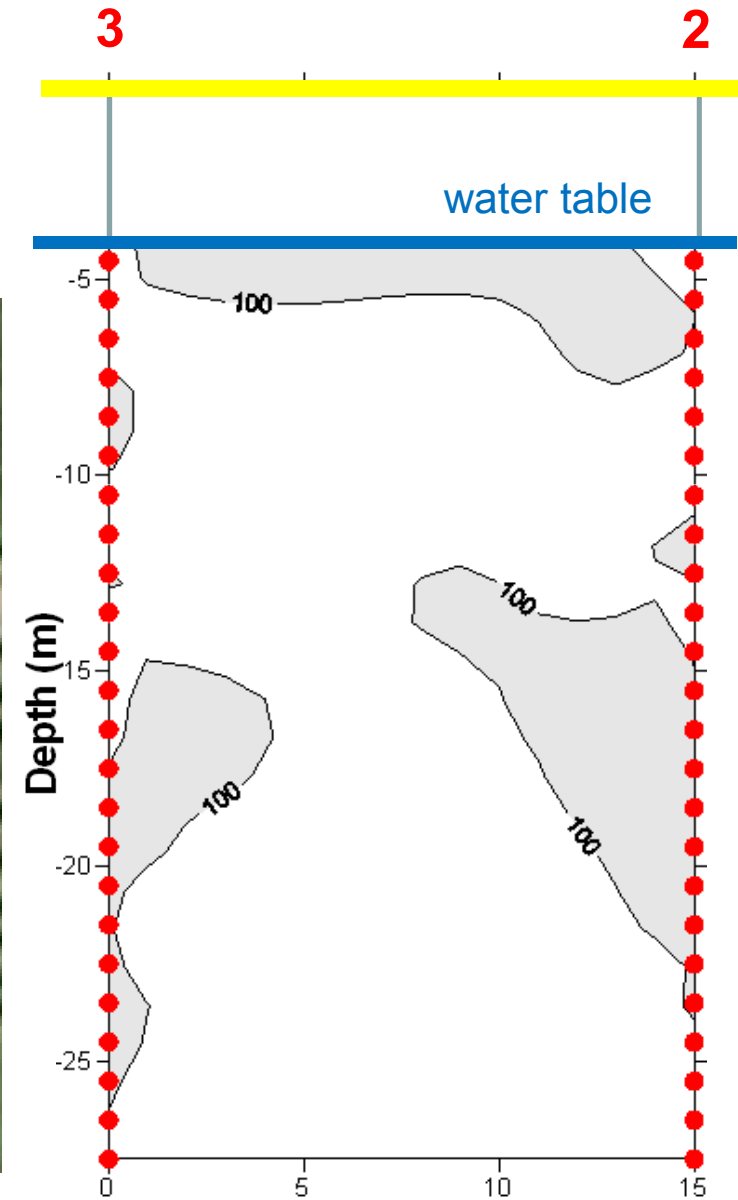
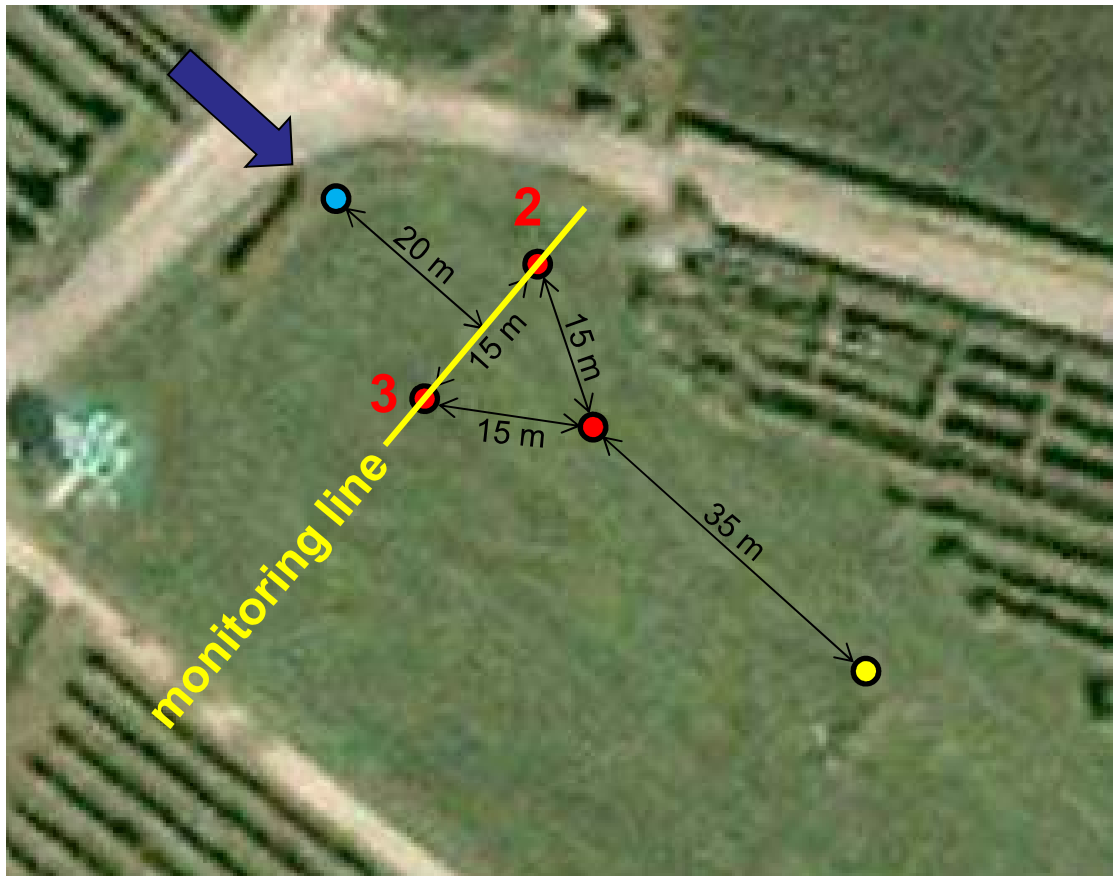
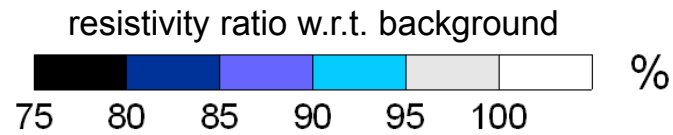
saline tracer test to identify
travel times and hydraulic conductivity structure





EXPERIMENTAL TEST AREA – Valdobbadiene – NE Italy

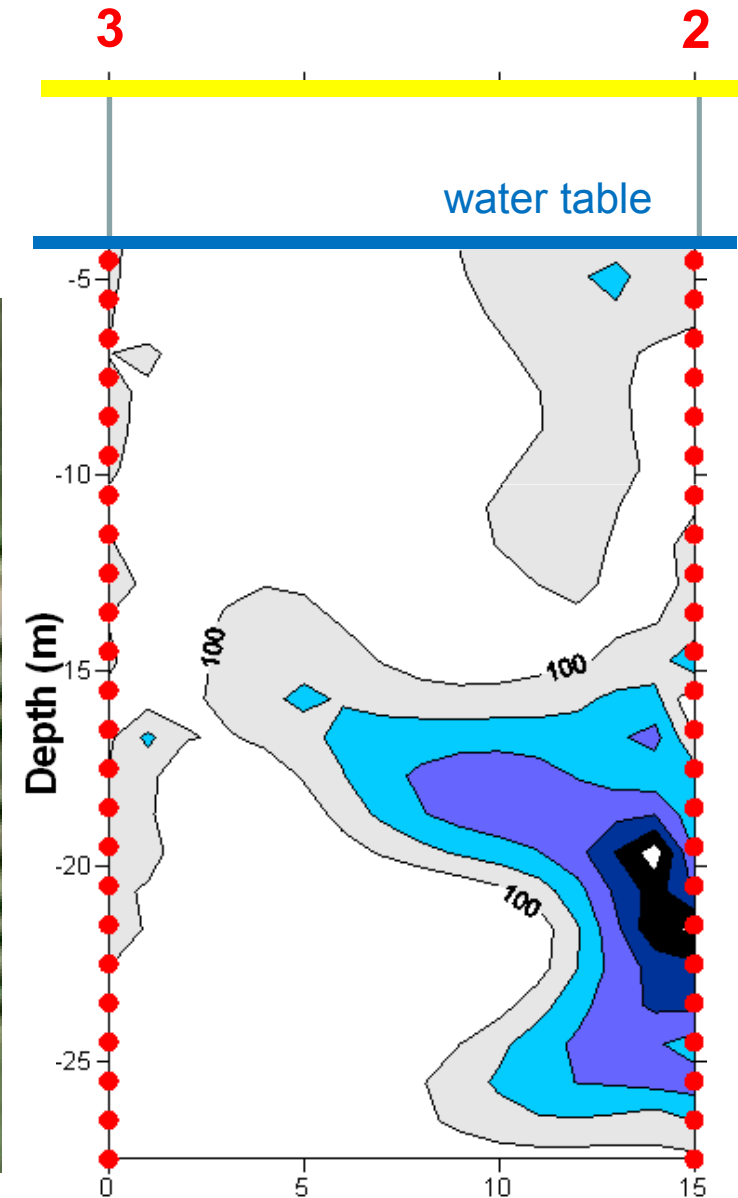
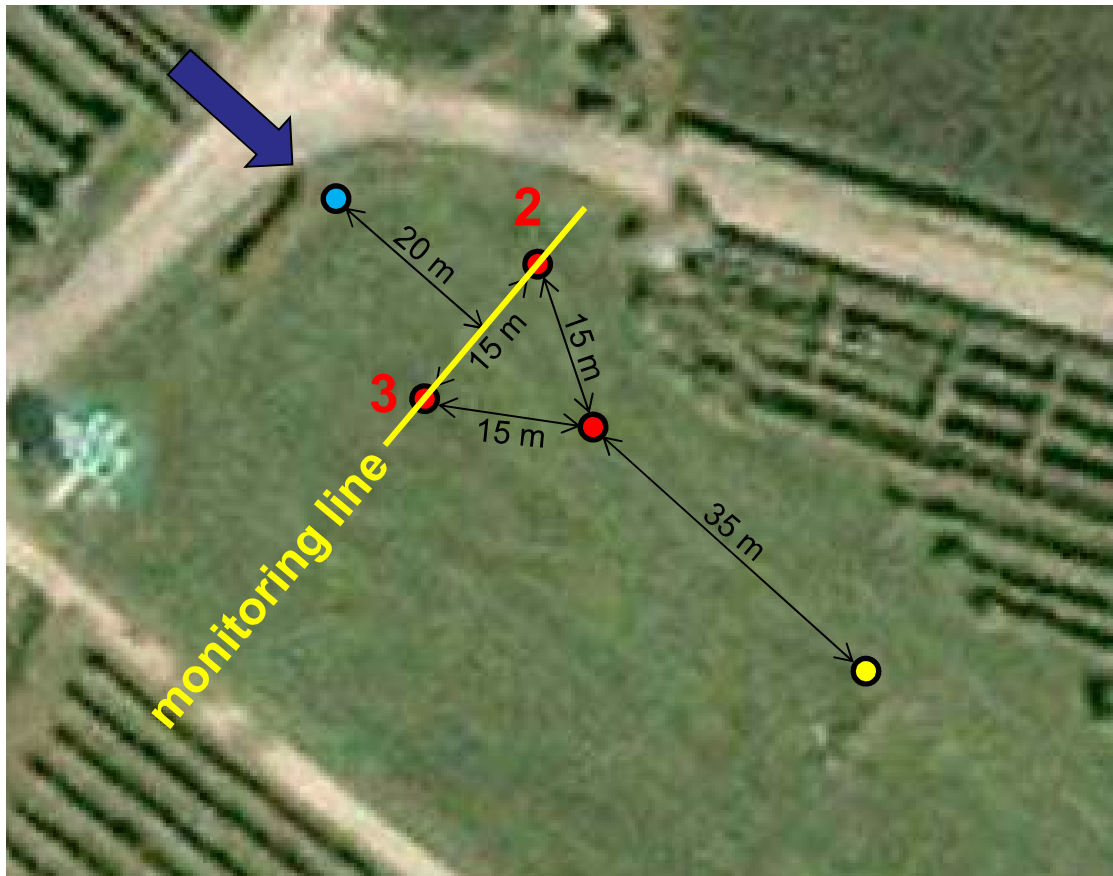
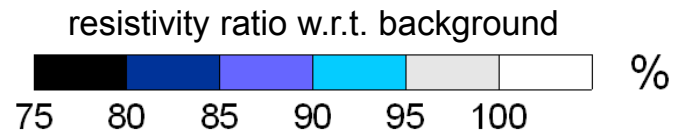
Time **1** (hh:mm): **00:34** after injection





EXPERIMENTAL TEST AREA – Valdobbadiene – NE Italy

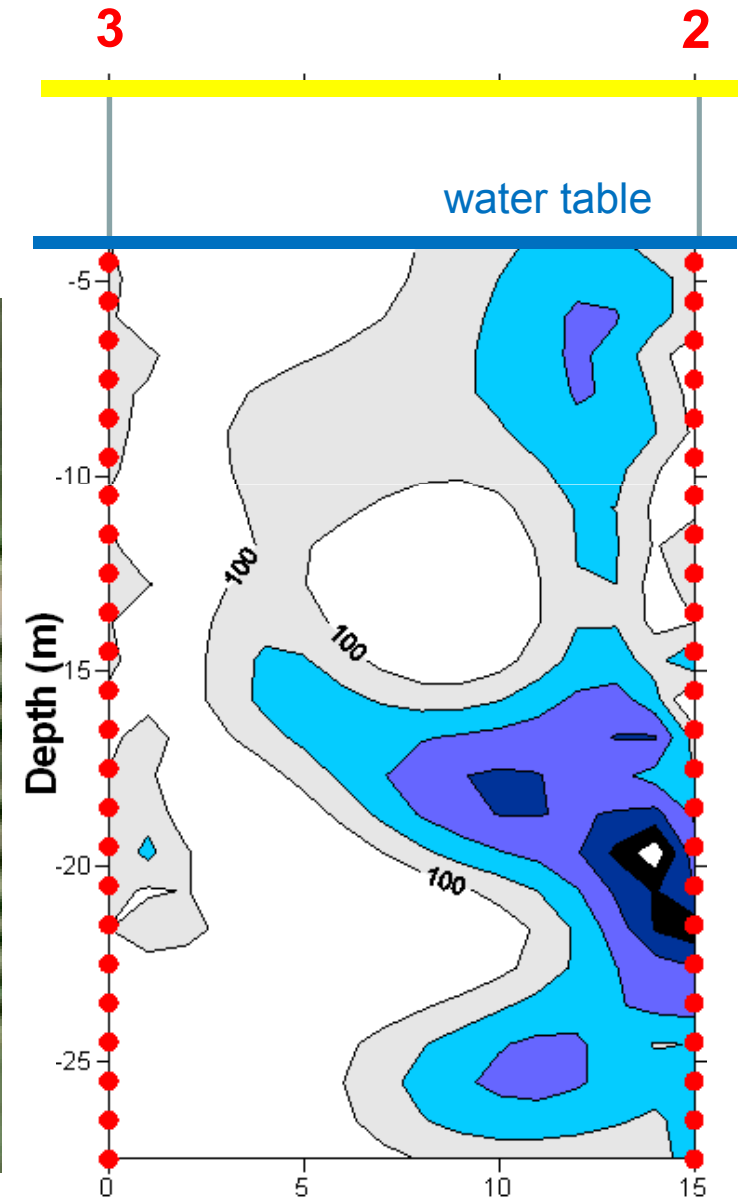
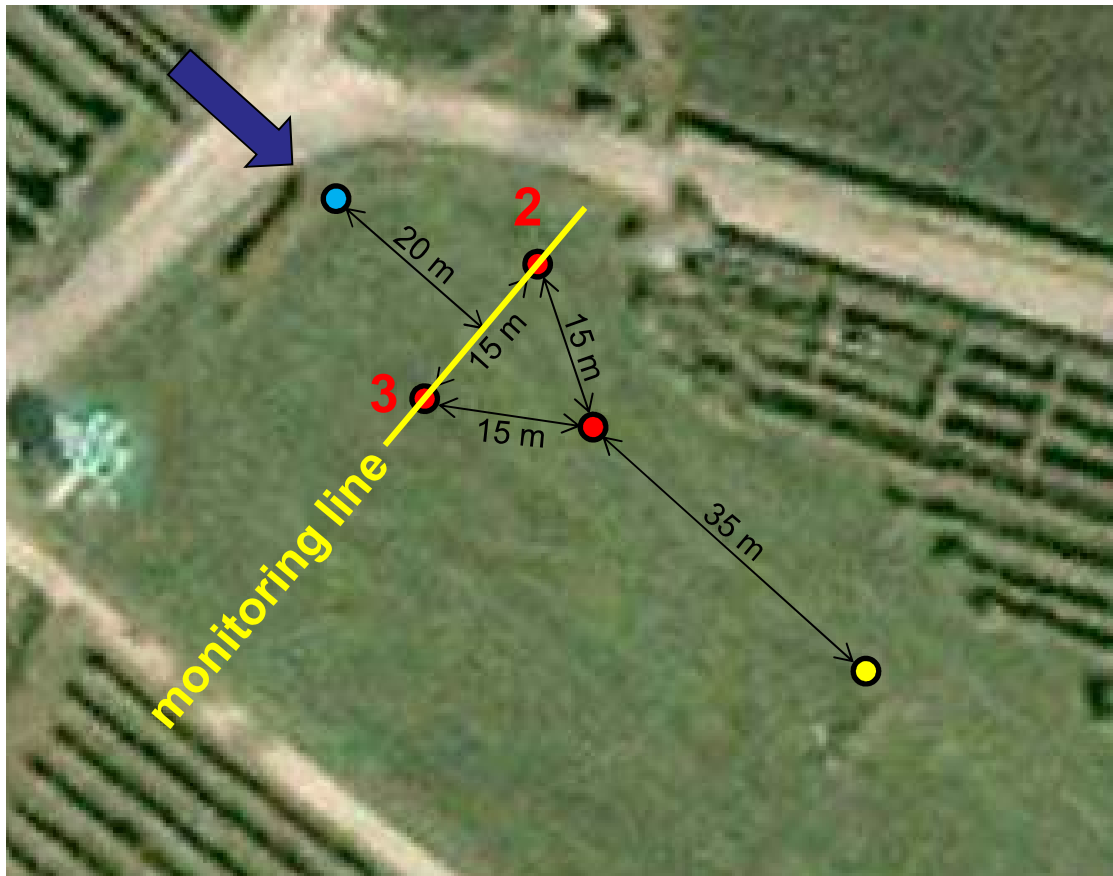
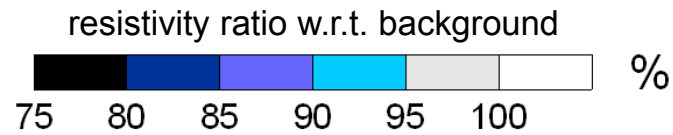
Time 4 (hh:mm): **03:27** after injection





EXPERIMENTAL TEST AREA – Valdobbiadene – NE Italy

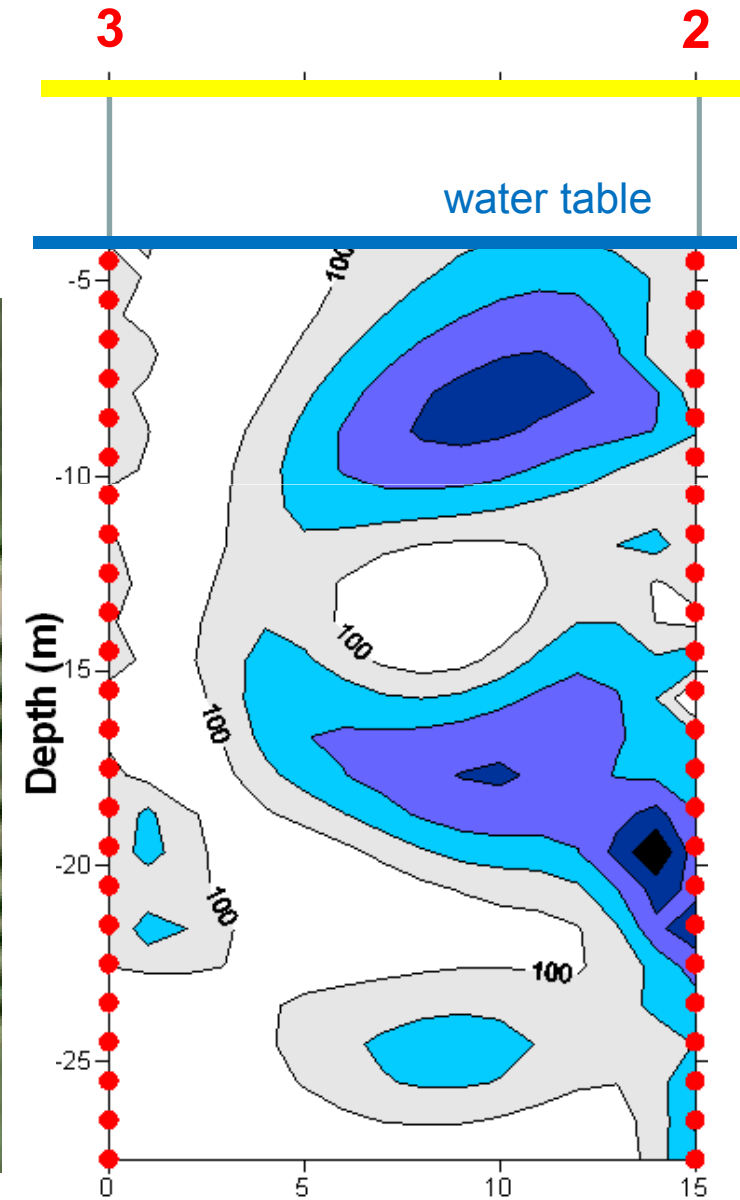
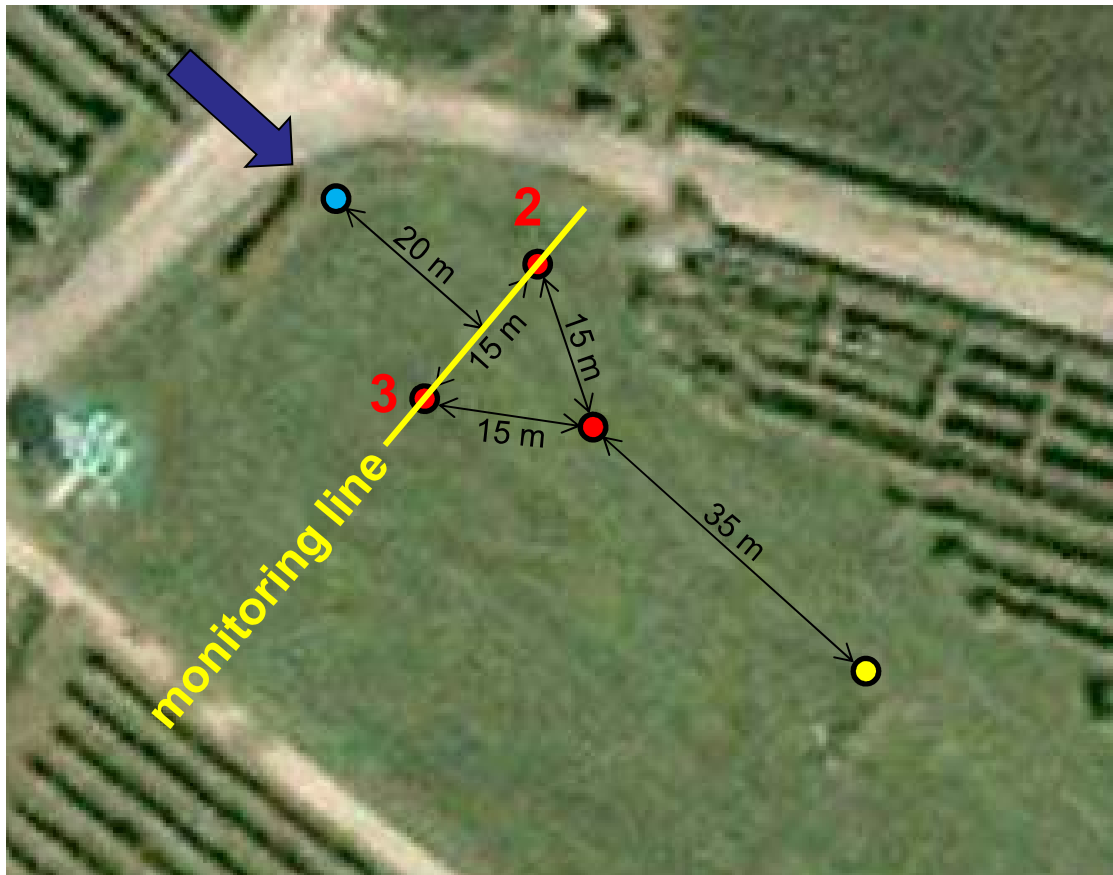
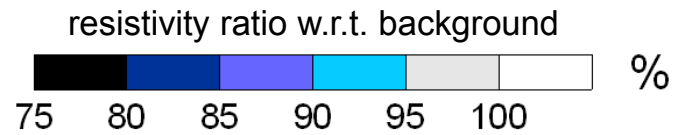
Time **7** (hh:mm): **05:57** after injection





EXPERIMENTAL TEST AREA – Valdobbadiene – NE Italy

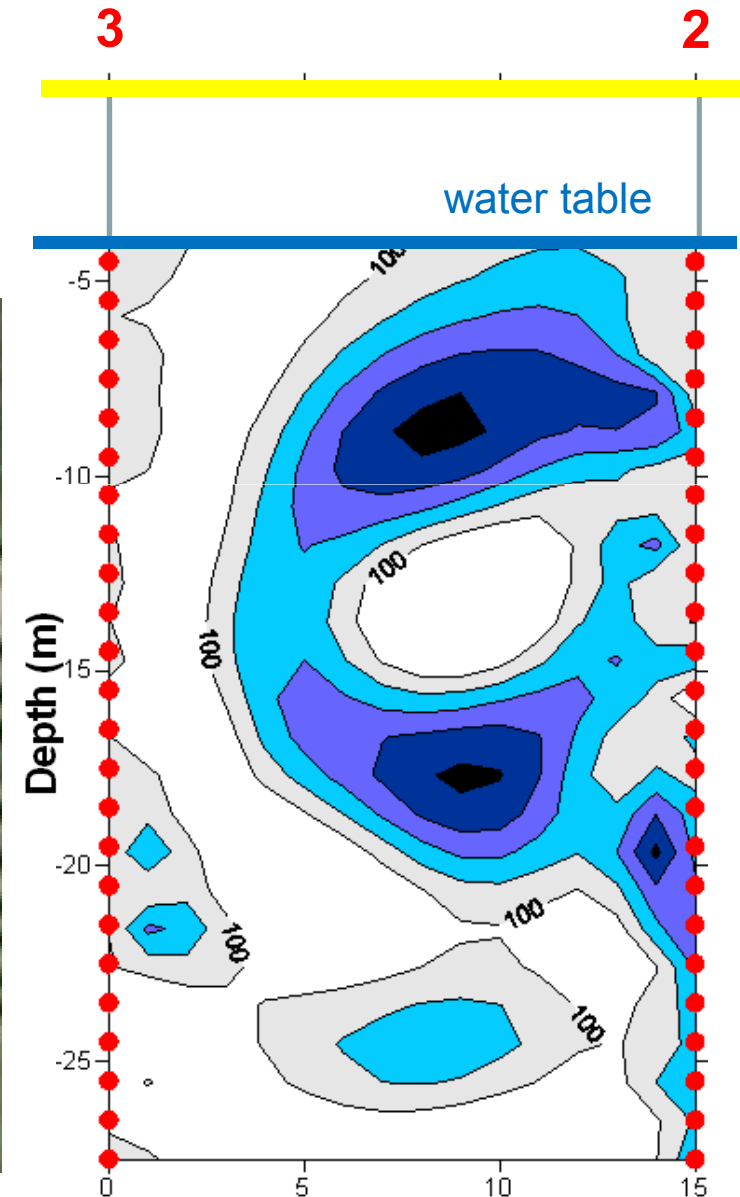
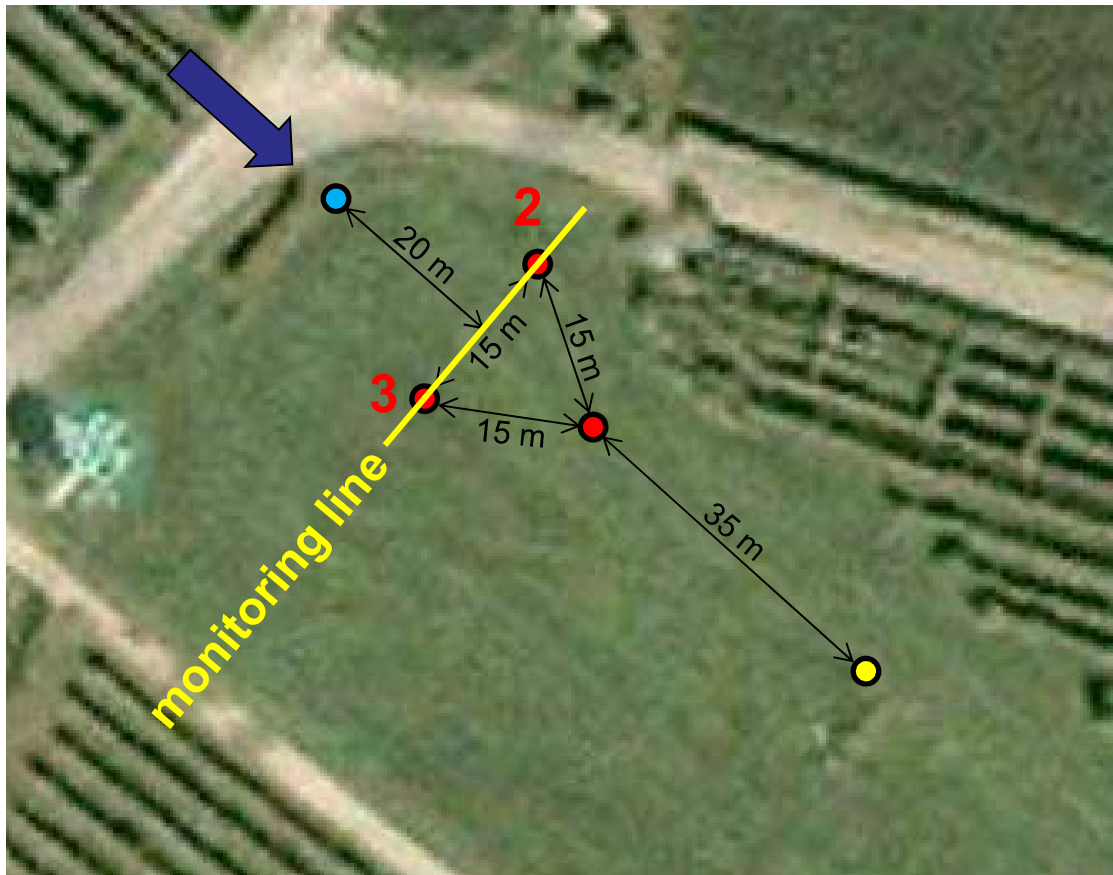
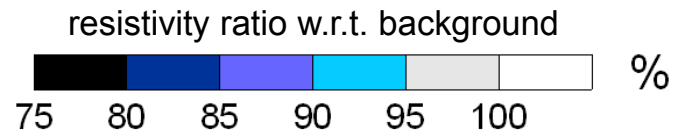
Time **10** (hh:mm): **08:28** after injection





EXPERIMENTAL TEST AREA – Valdobbadiene – NE Italy

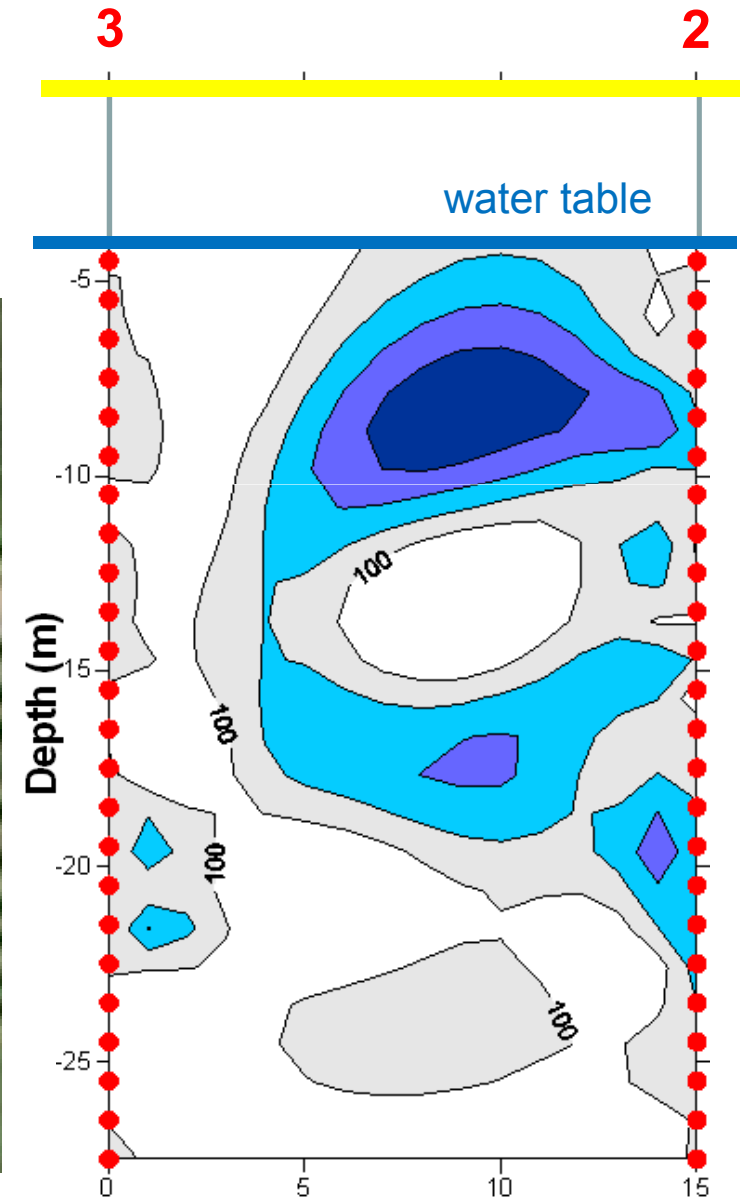
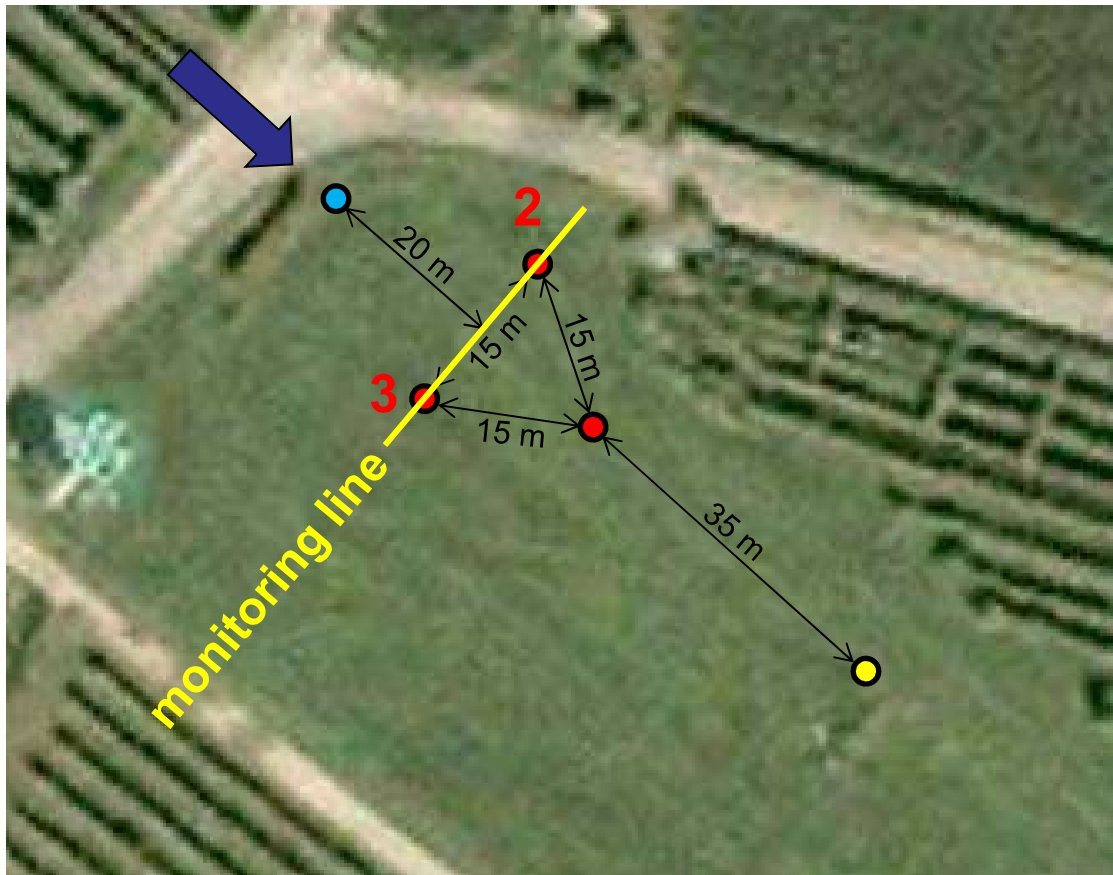
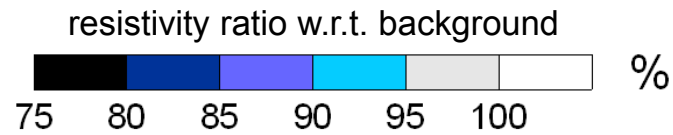
Time **13** (hh:mm): **11:30** after injection





EXPERIMENTAL TEST AREA – Valdobbadiene – NE Italy

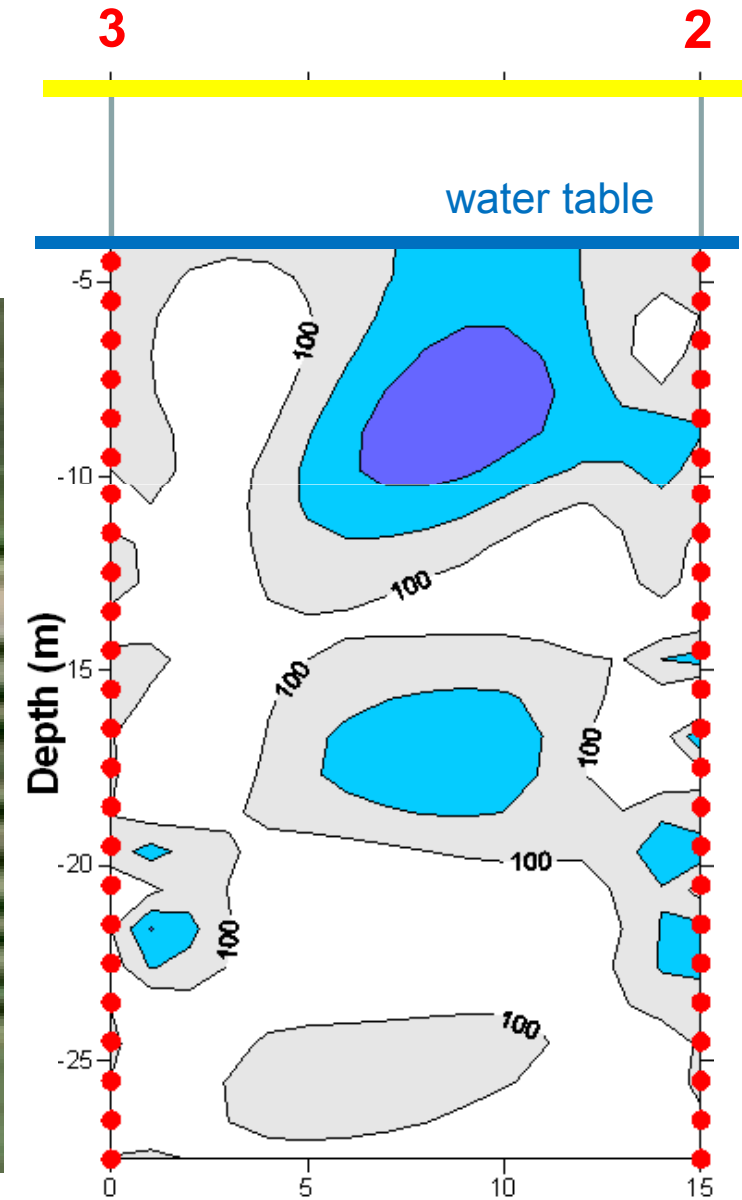
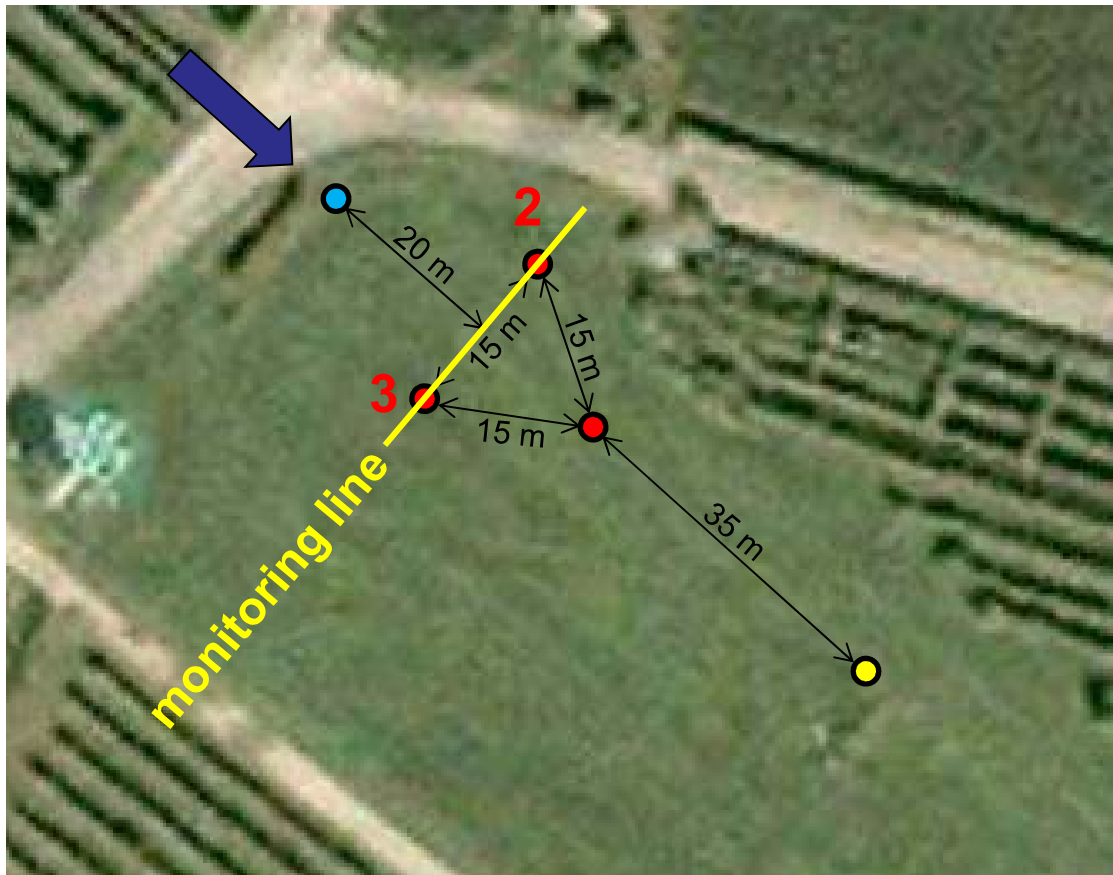
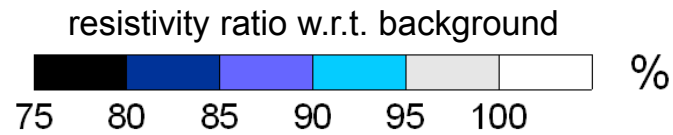
Time **21** (hh:mm): **21:43** after injection





EXPERIMENTAL TEST AREA – Valdobbadiene – NE Italy

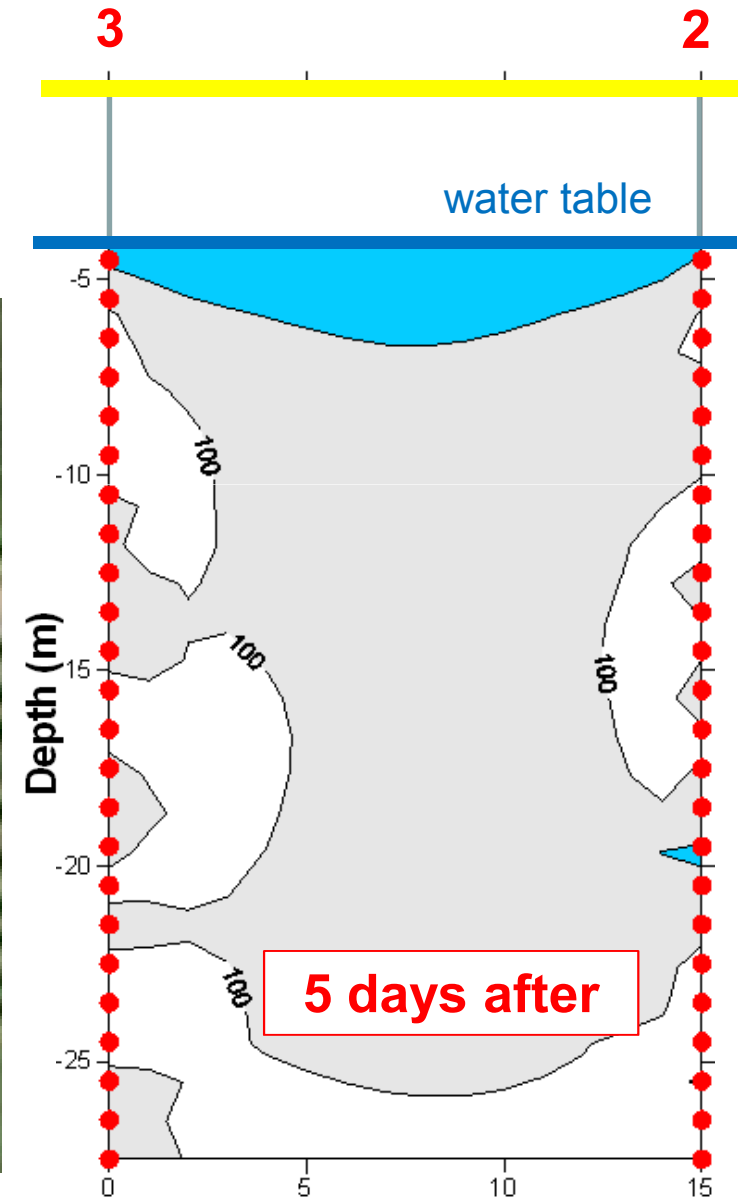
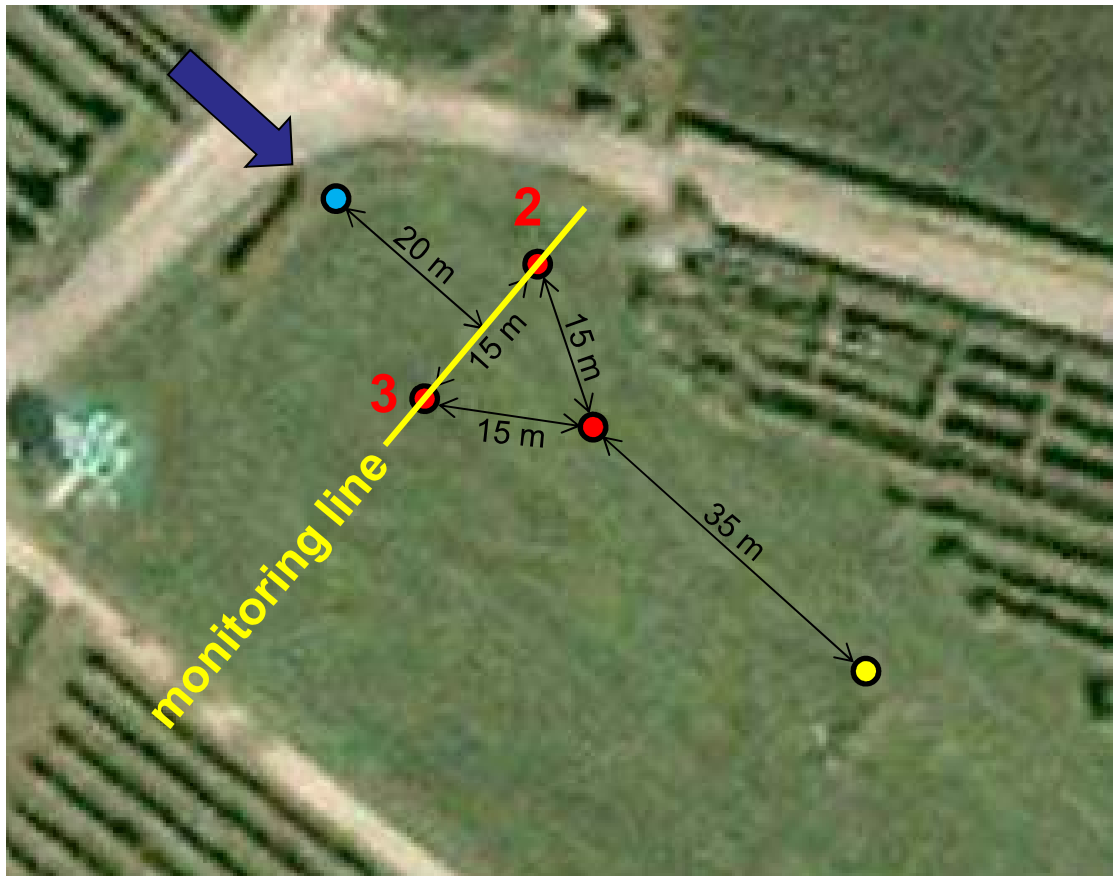
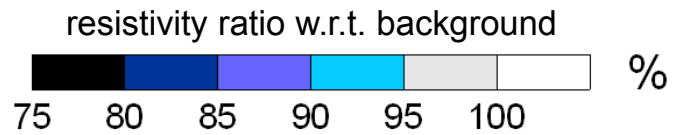
Time **26** (hh:mm): **54:27** after injection





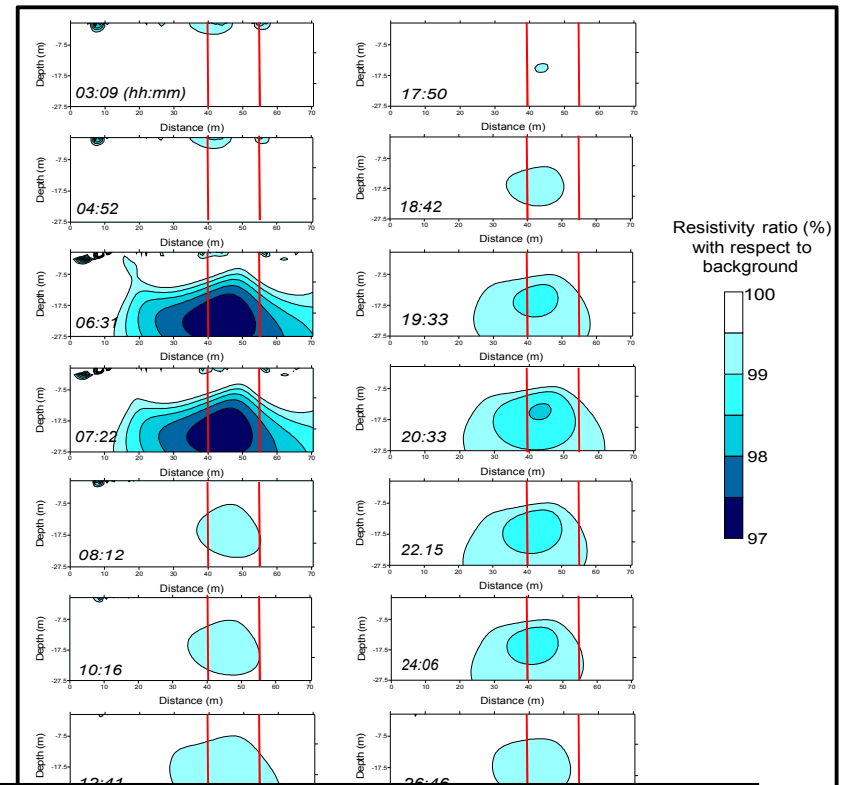
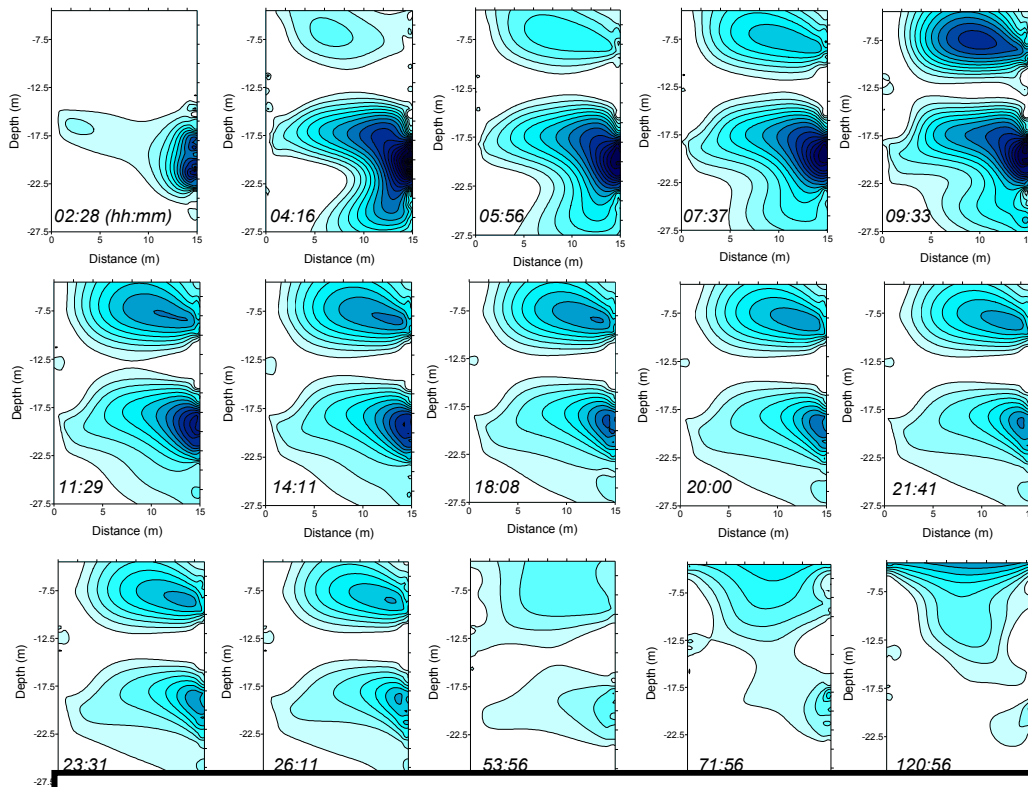
EXPERIMENTAL TEST AREA – Valdobbadiene – NE Italy

Time **28** (hh:mm): **122:20** after injection





INFORMATION CONTENT IN TRACER TEST EXPERIMENTS MONITORED WITH ERT



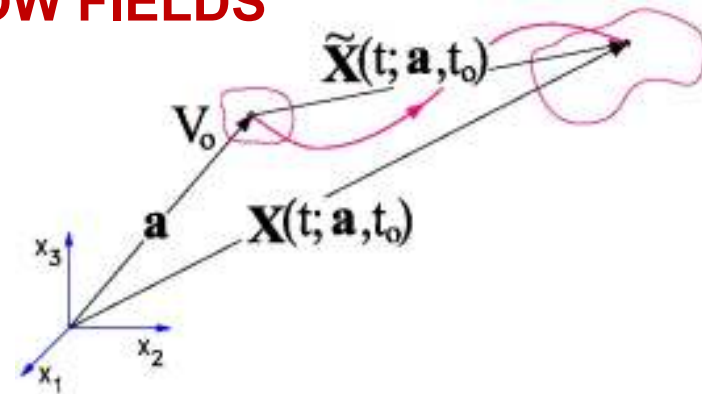
HOW CAN WE EXTRACT THE INFORMATION CONTAINED IN THESE DATA ?



MODELLING TRANSPORT IN SPATIALLY HETEROGENEOUS FLOW FIELDS

Lagrangian analysis of a conservative solute
for high Peclet number values (we can neglect
pore dispersion effects)

$$\mathbf{X}(t; \mathbf{a}, t_0) = \mathbf{a} + \int_{t_0}^t \mathbf{v}[\mathbf{X}(t'; \mathbf{a}, t_0)] dt' = \mathbf{a} + \tilde{\mathbf{X}}(t; \mathbf{a}, t_0)$$



If the spatial distribution of the initial concentration is assumed to be known:

$$M = n \int_{V_0} C_0(\mathbf{x}) d\mathbf{x} \quad \bar{C}(\mathbf{x}, t) = \frac{n}{M} \int_{\Delta V} C(\mathbf{x}, t) d\mathbf{x}$$

where M is the total mass of contaminant, n is porosity (assumed constant), C_0 is the initial concentration (constant in the volume V_0), and ΔV is the voxel volume

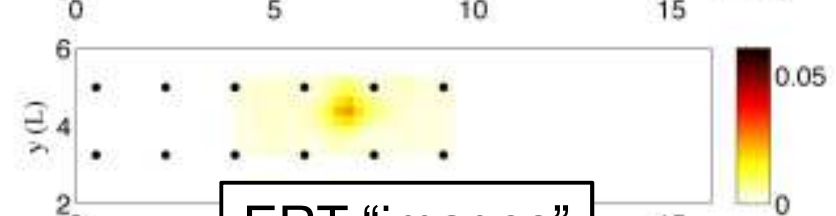
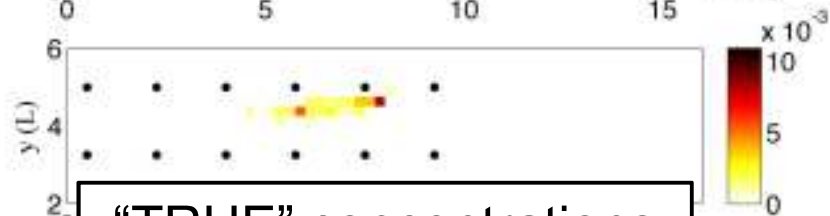
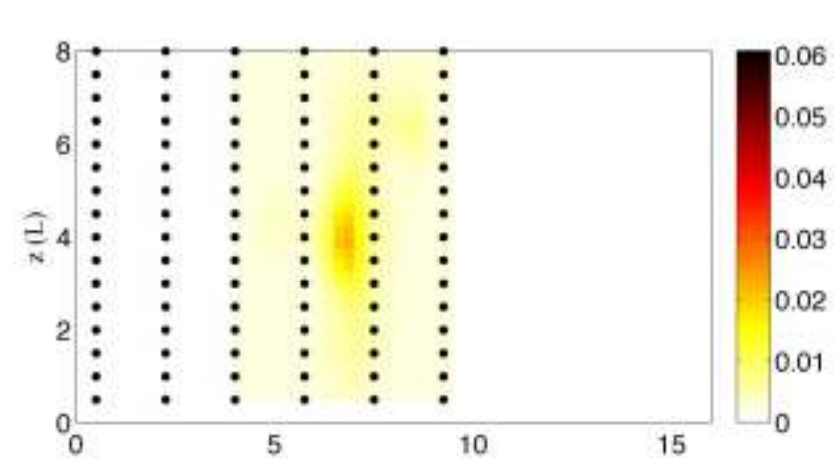
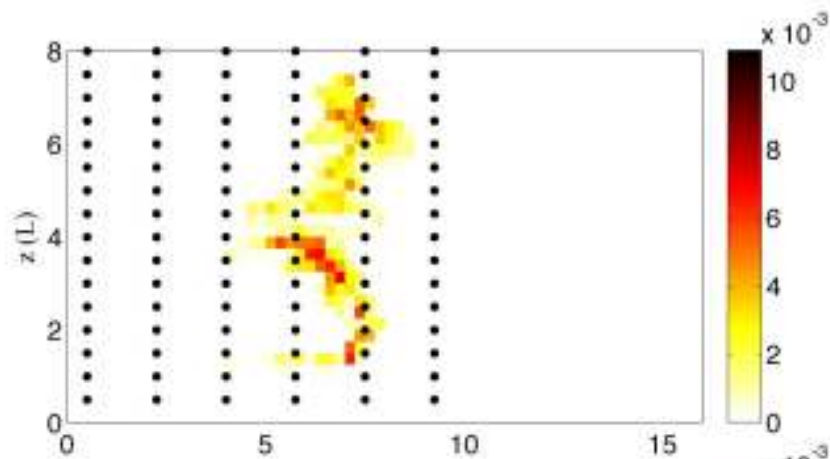
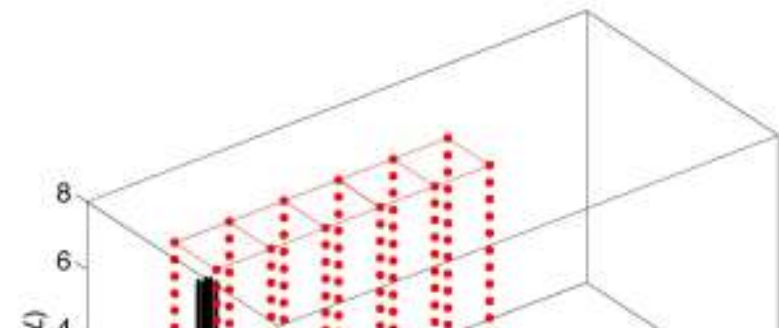
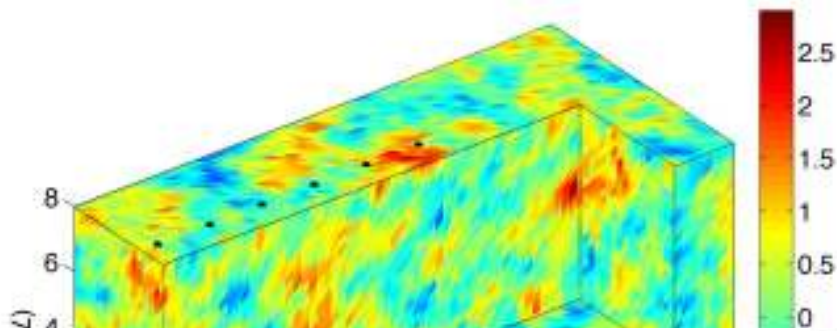
The plume evolution is described on the basis of the knowledge of the plume dimensionless concentration $\bar{C}(\mathbf{x}, t)$

$\bar{C}(\mathbf{x}, t)$ is controlled by the particles' trajectories, depending on the spatial variability of hydraulic conductivity



SYNTHETIC TEST CASE

$$K_G = 1.00 \text{ [L/T]} \ (\langle Y \rangle = 0.0, \sigma^2_Y = 0.5), \lambda_h = \lambda_v = 1.0 \text{ [L]}$$
$$V_0 = \pi \times 0.5^2 / 4 \times 5.625 \text{ [L}^3\text{]}, 1000 \text{ [particles/L}^3\text{]}$$



“TRUE” concentrations

ERT “images”



The ensemble Kalman filter

$i = 1, \dots, \text{number of time instants}; j = 1, \dots, \text{number of Monte Carlo realizations}$

$n = \text{number of cells}; Y = \log(K), K = \text{hydraulic conductivity}$

State Eq.: $y^j(t) = F[y^j(\tau), \beta^j] \quad t_0 \leq \tau < t; \quad y_0^j = y^j(t_0); j = 1, \dots, NMC$

Meas Eq.: $z_i^j = O[y^j, \omega_i^j, t_i] \quad ; \quad i = 1, \dots, n_{\text{times}}; \omega_i^j = \text{random noise term (meas error)}$

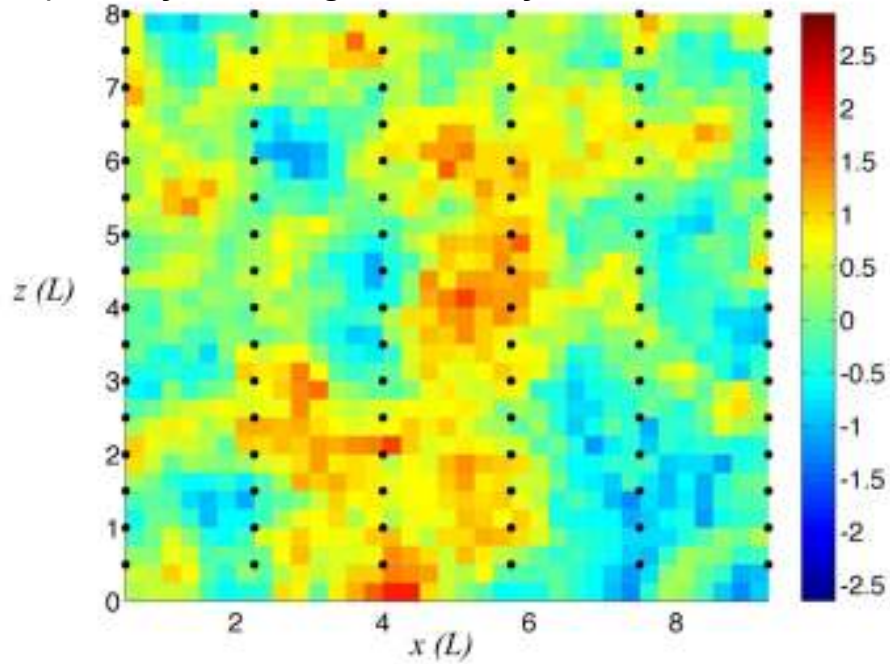
Update Eq.:
$$\begin{cases} y^j(t_{i+1} | Z_{i+1}) = y^j(t_{i+1} | Z_i) + K_{i+1} \{z_{i+1}^j - O[y^j(t_{i+1} | Z_i)]\} \\ \mathbf{K}_{i+1} = \mathbf{C}_{yy}(t_{i+1} | Z_i) \mathbf{H}^T [\mathbf{H} \mathbf{C}_{yy}(t_{i+1} | Z_i) \mathbf{H}^T + \mathbf{C}_{\omega\omega}]^{-1}; \mathbf{H} \text{ linearizes } O \end{cases}$$

$$y = \begin{bmatrix} C_1 \\ \vdots \\ C_n \\ Y_1 \\ \vdots \\ Y_n \end{bmatrix} \left. \vphantom{\begin{bmatrix} C_1 \\ \vdots \\ C_n \\ Y_1 \\ \vdots \\ Y_n \end{bmatrix}} \right\} 2n$$

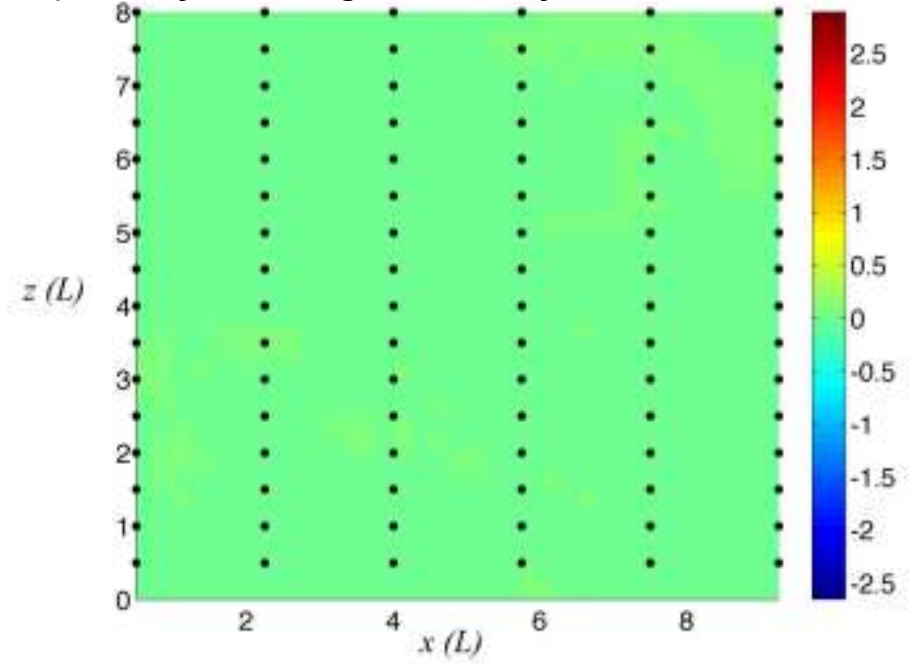
$$\beta = \begin{bmatrix} Y_1 \\ \vdots \\ Y_n \end{bmatrix}$$

$$z = \begin{bmatrix} \sigma_1 \\ \vdots \\ \sigma_m \end{bmatrix} \left. \vphantom{\begin{bmatrix} \sigma_1 \\ \vdots \\ \sigma_m \end{bmatrix}} \right\} \begin{array}{l} m \\ \text{observations} \\ \text{of electrical} \\ \text{conductivity} \end{array}$$

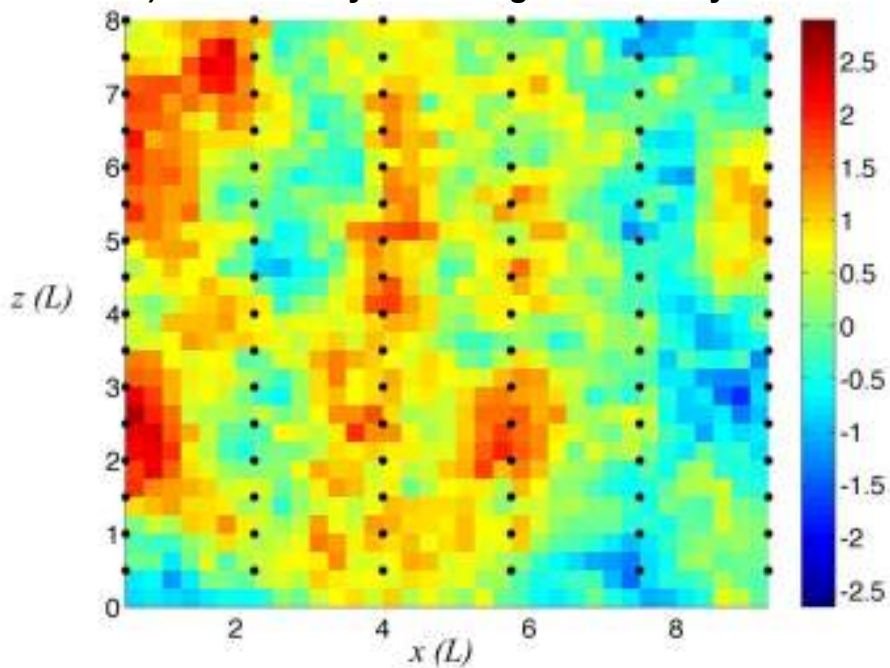
a) True hydraulic log-conductivity field



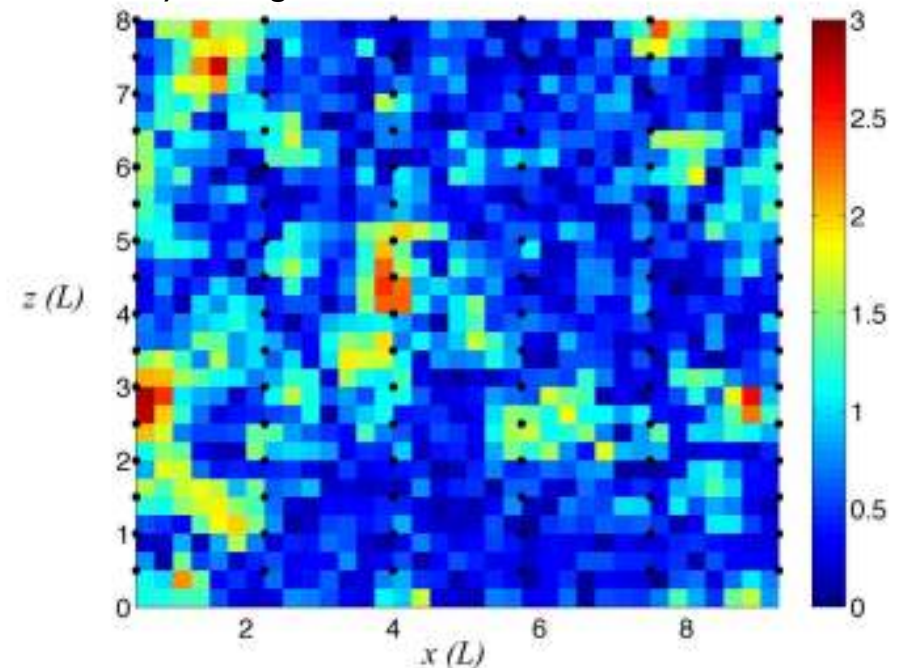
b) Prior hydraulic log-conductivity field



c) Estimated hydraulic log-conductivity field

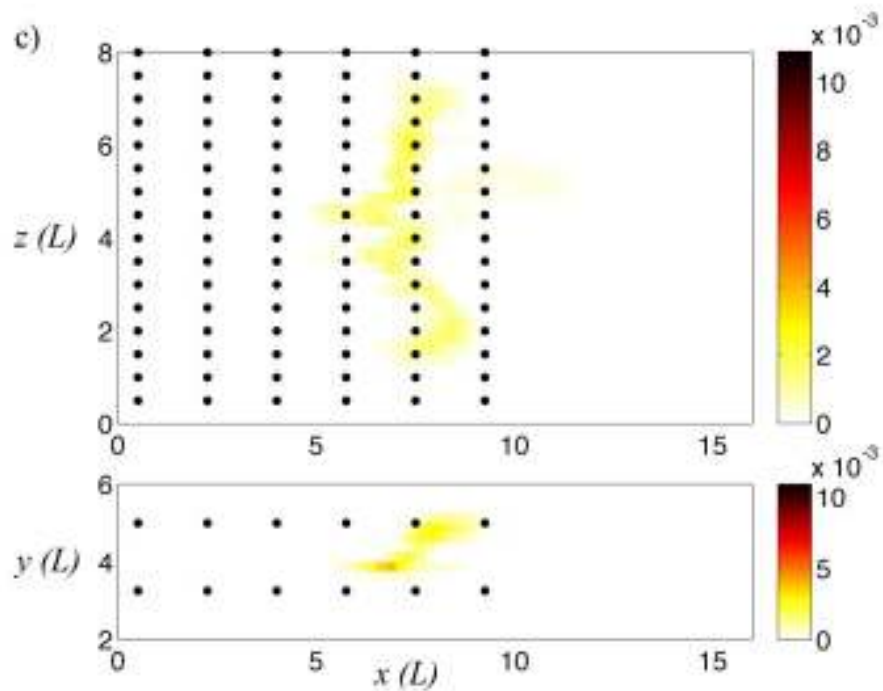
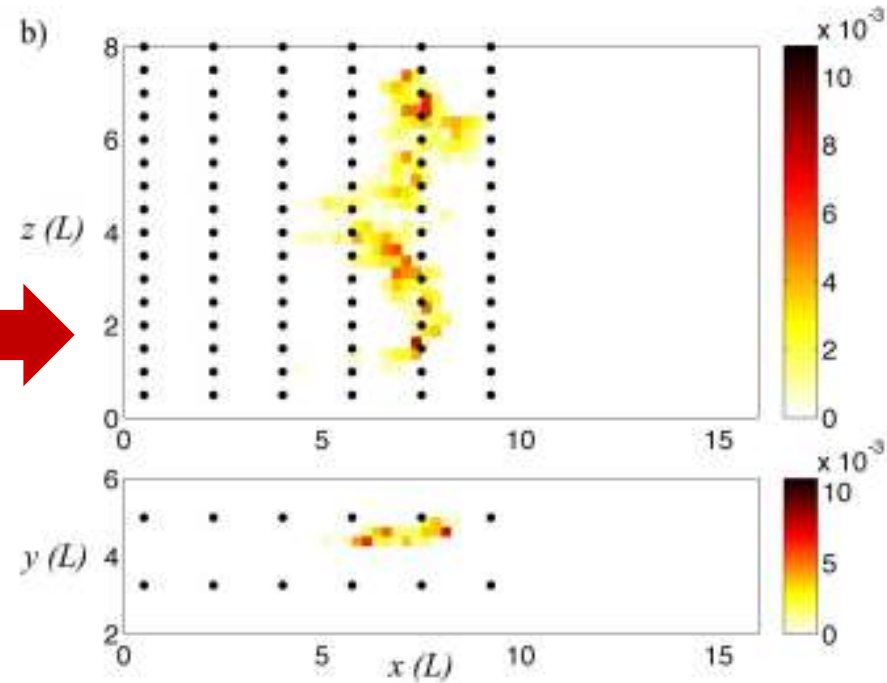
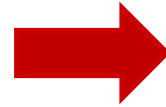


d) Average absolute error of estimation





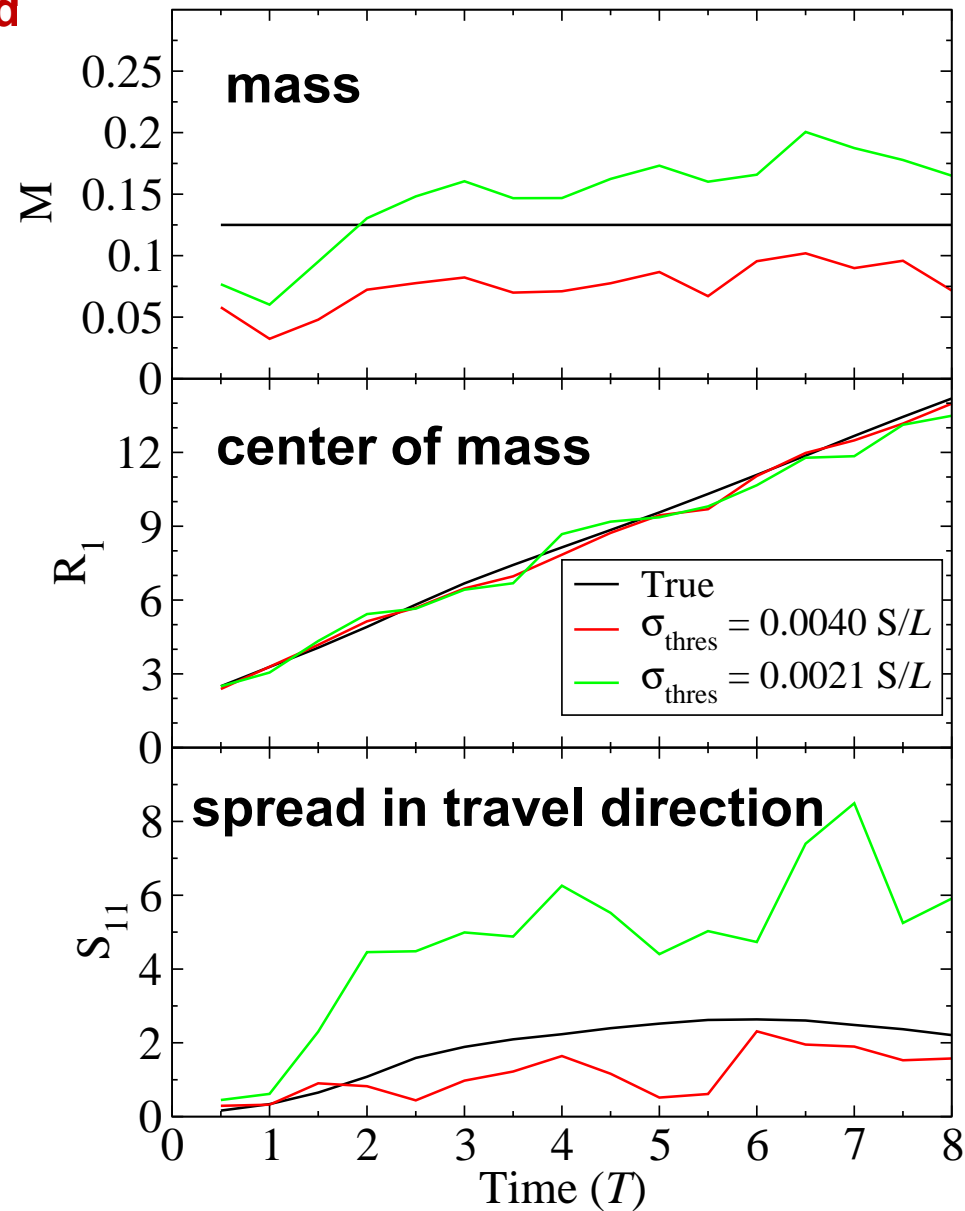
Tracer plume at $t = 8.0$ T simulated with the true hydraulic conductivity field



Tracer plume at $t = 8.0$ T simulated with the estimated hydraulic conductivity field



Plume moments and filter performance



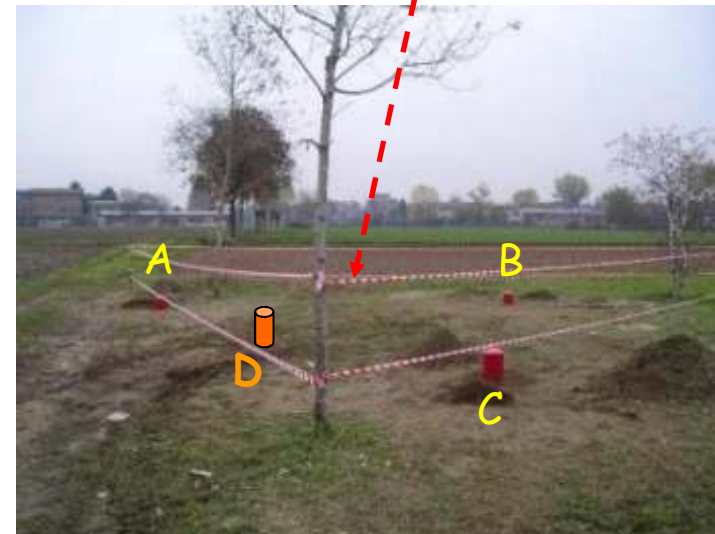
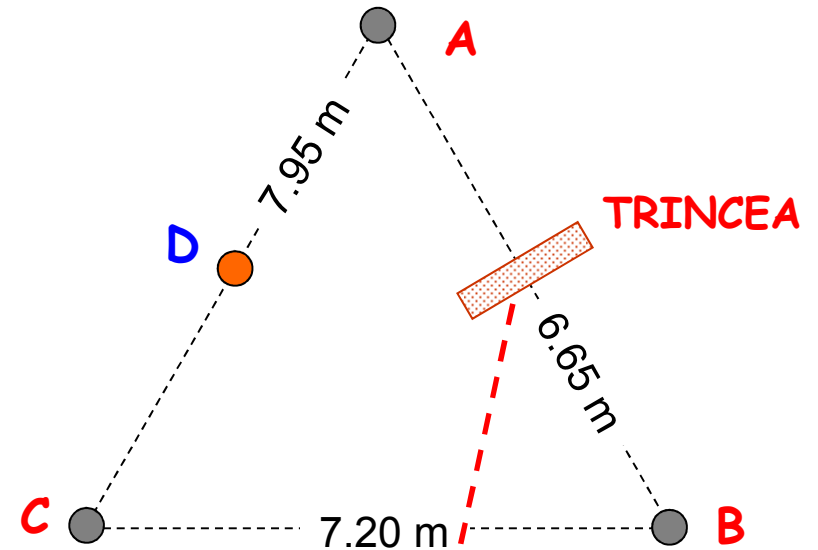




CARATTERIZZAZIONE DINAMICA DEL NON SATURO SOTTO FORZANTI ARTIFICIALI

Worskhop di Geofisica e
ata di Formazione - MCR

Il sito sperimentale di Gorgonzola (MI)

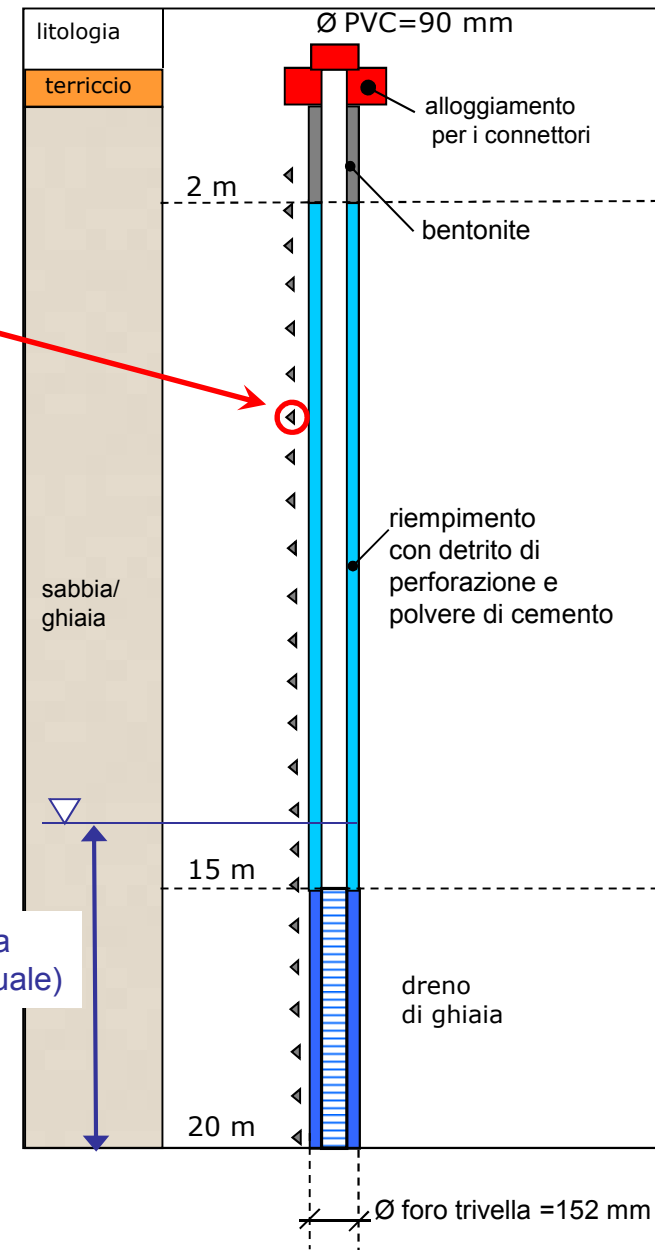
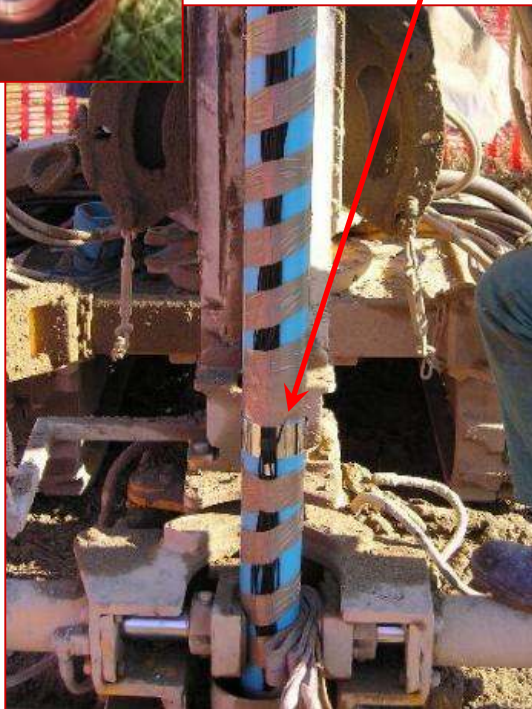




Il sito sperimentale di Gorgonzola (MI)



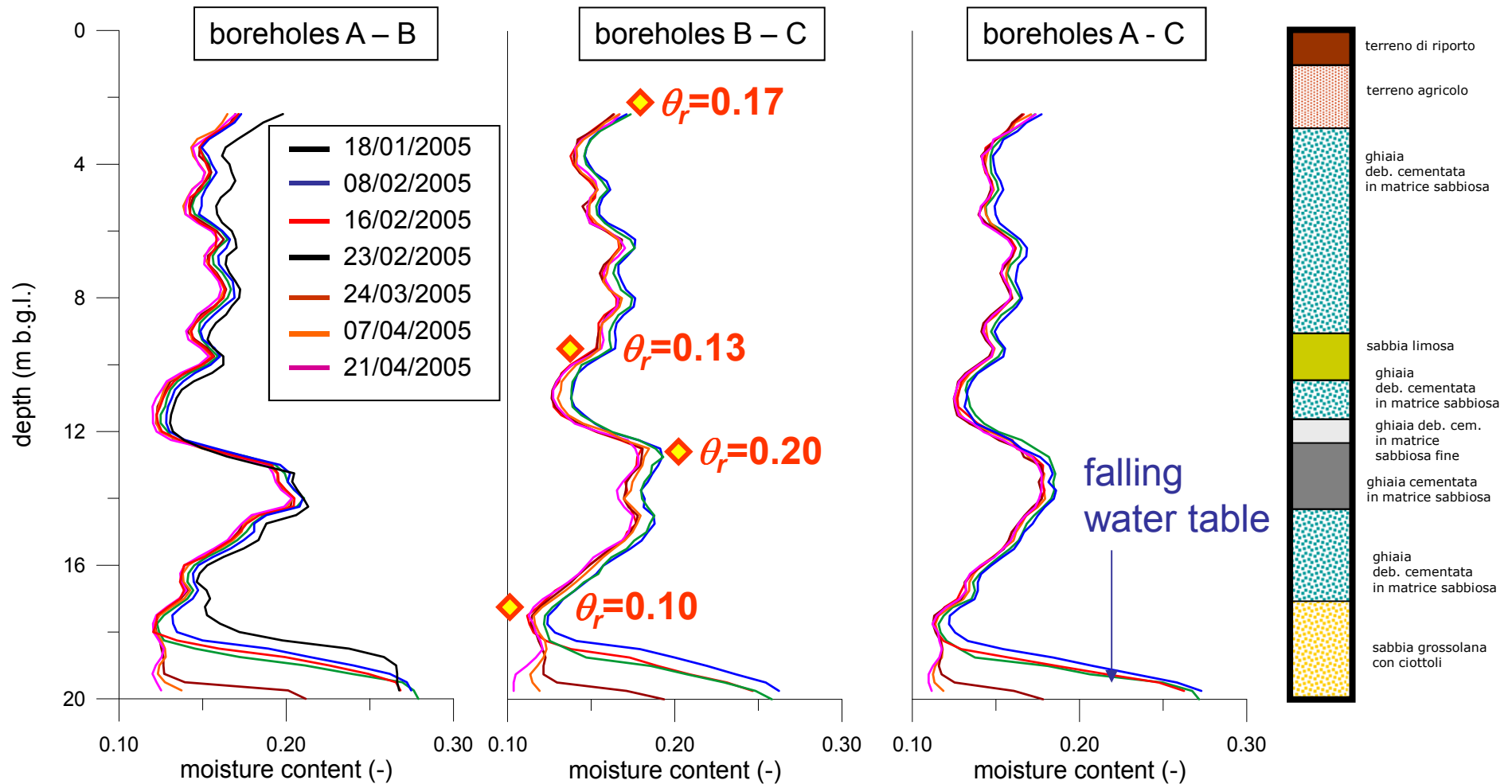
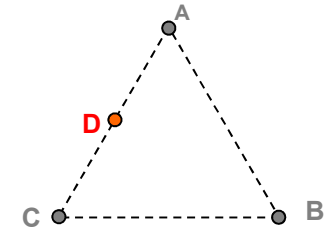
24 elettrodi spaziat
0.8 m





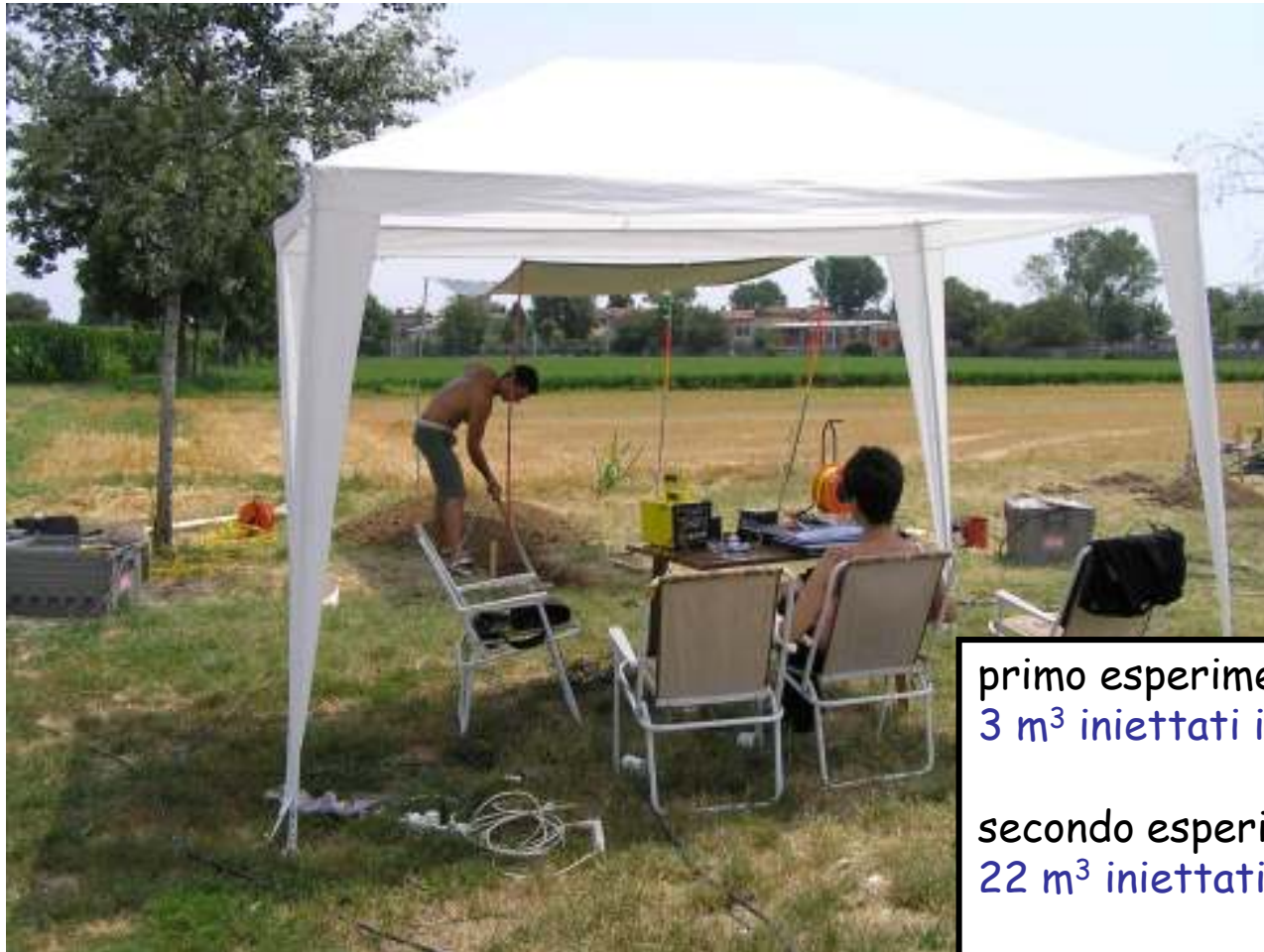
Misure di background: contenuto idrico da GPR ZOP

◆ valori di contenuto idrico residuo da laboratorio





Sito di Gorgonzola: esperimenti di iniezione d'acqua



primo esperimento (Luglio 2005):
3 m³ iniettati in 2 ore

secondo esperimento (Gennaio 2006):
22 m³ iniettati in 10 ore

terzo esperimento (Giugno 2007):
11 m³ iniettati in 6 ore

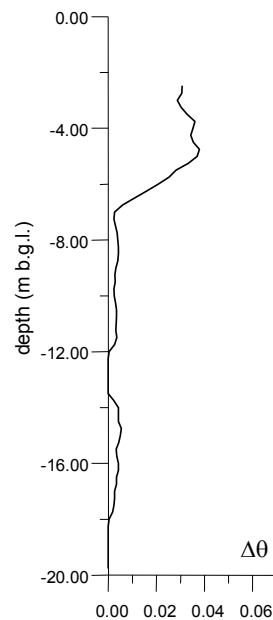


3 ore
dall'iniezione

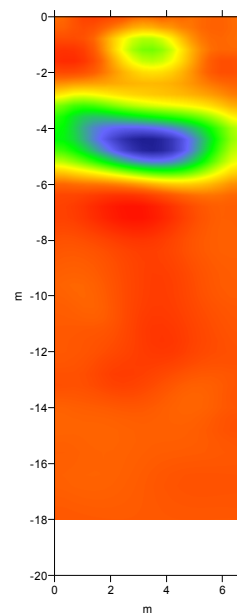
Secondo
esperimento:

variazioni del
contenuto
d'acqua
rispetto al
background

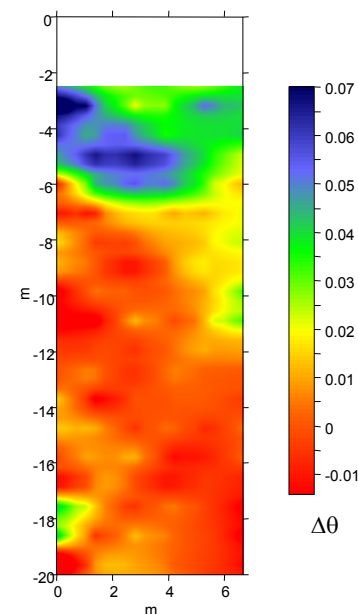
45 ore
dall'iniezione



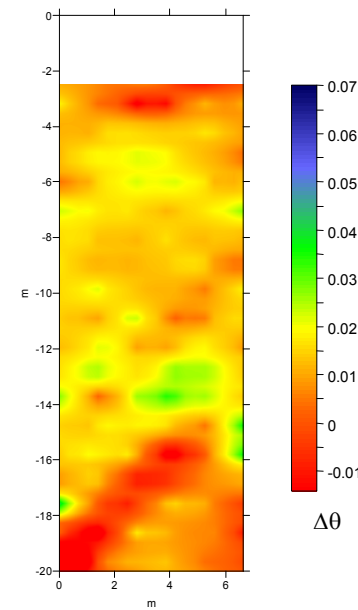
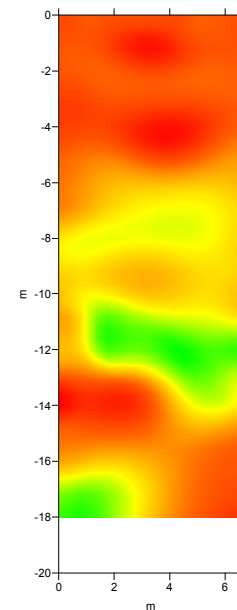
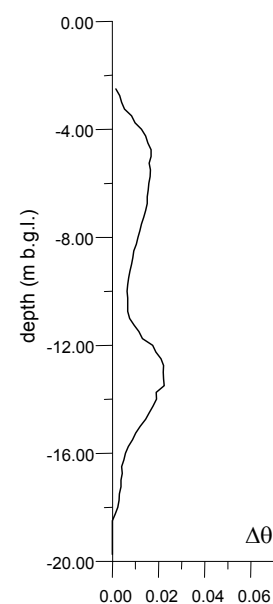
ZOP



ERT

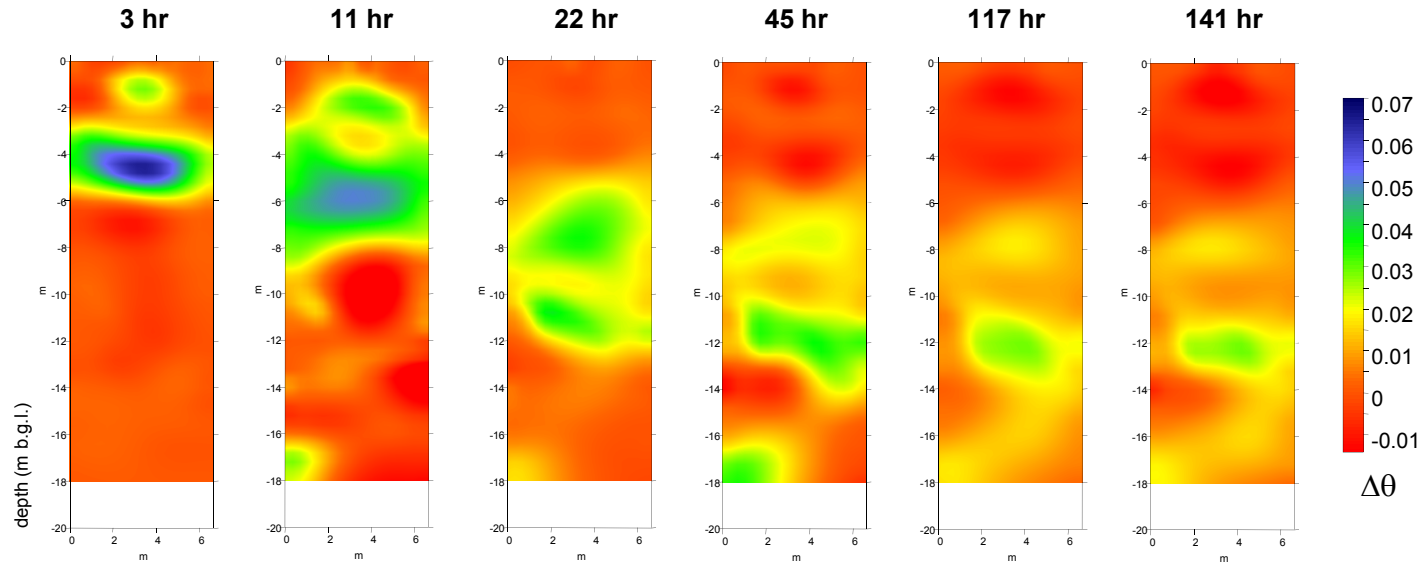


MOG

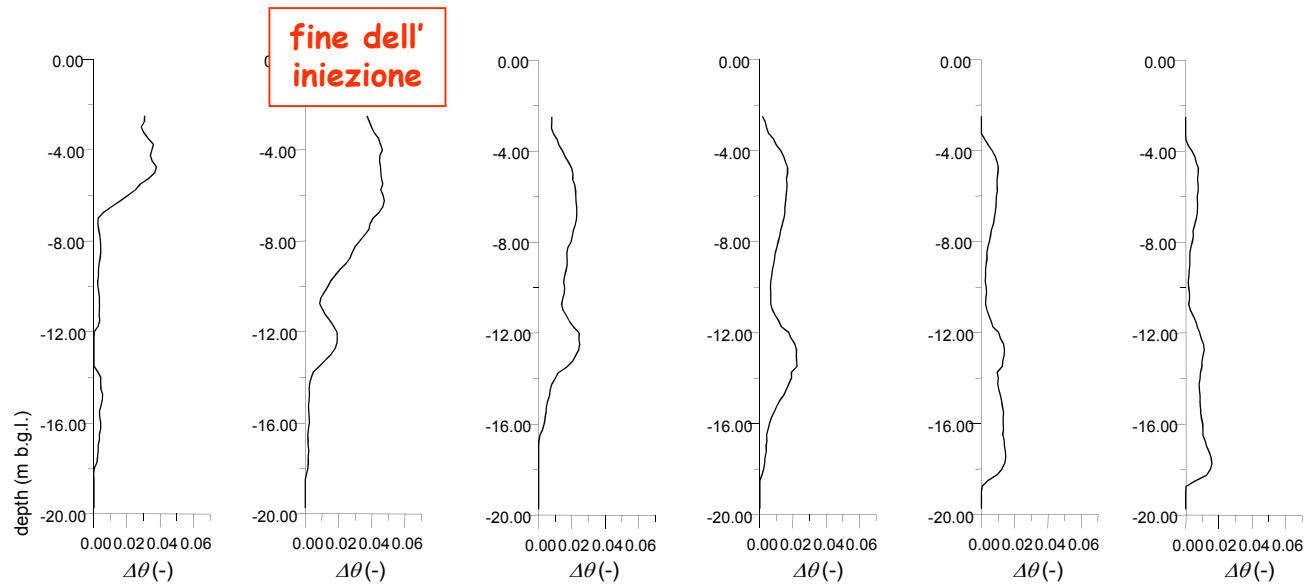




ERT

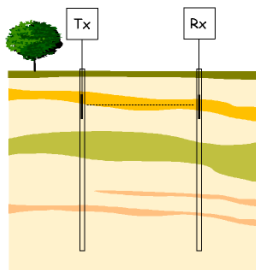
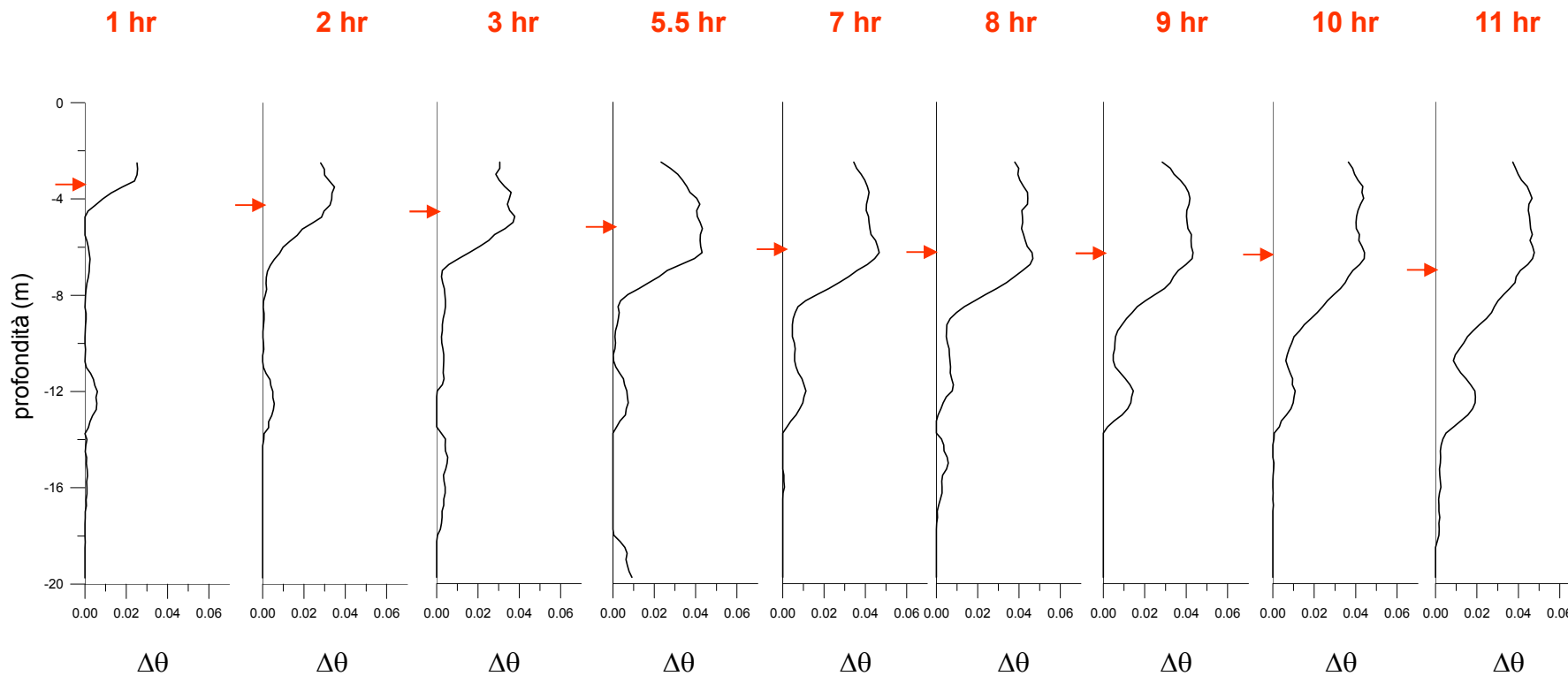


ZOP
GPR





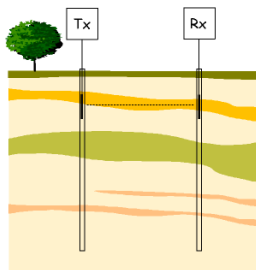
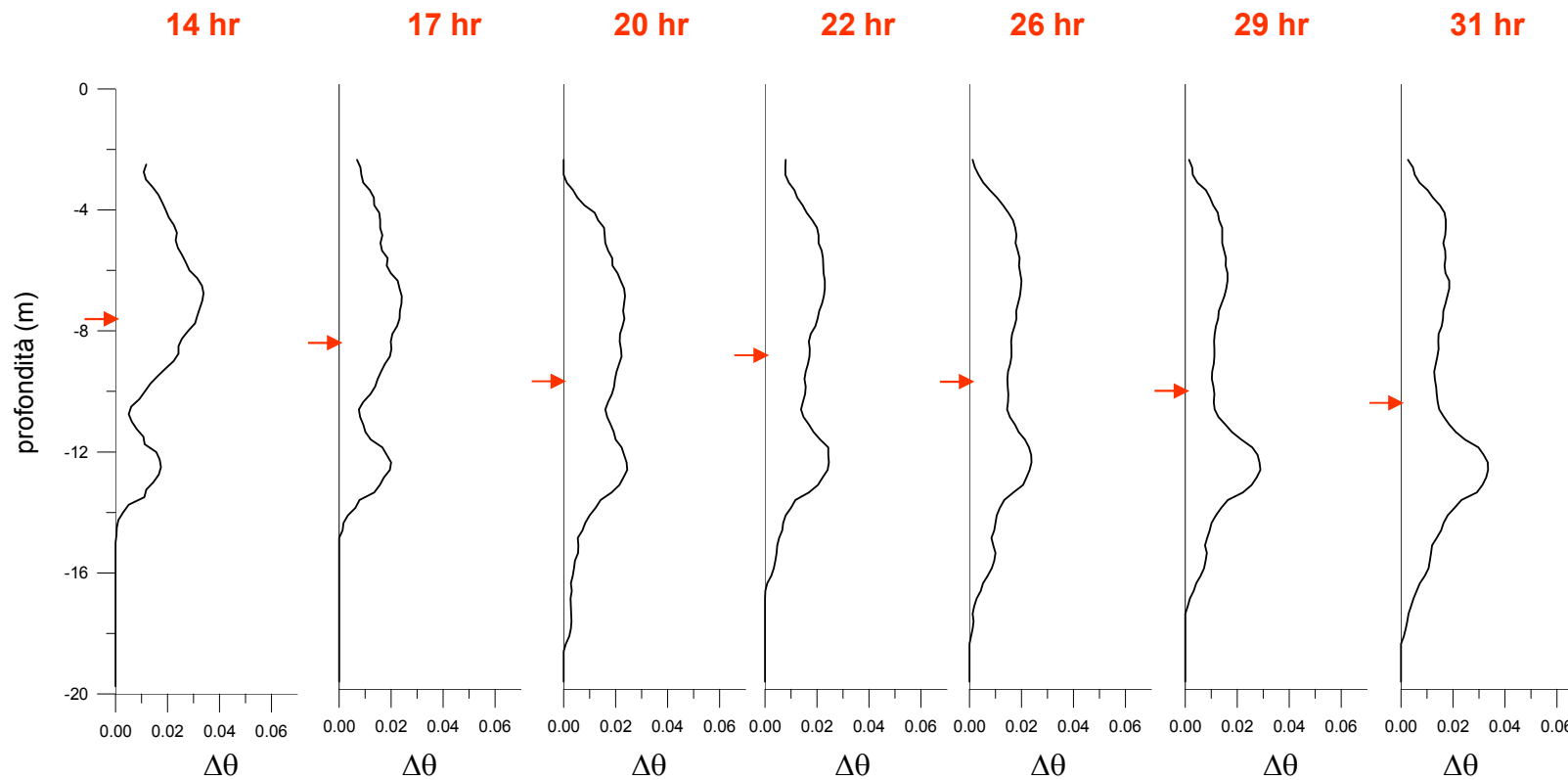
Fase di iniezione



zop GPR



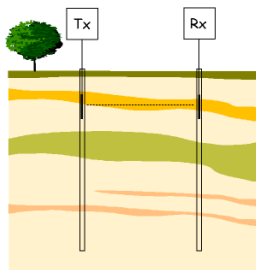
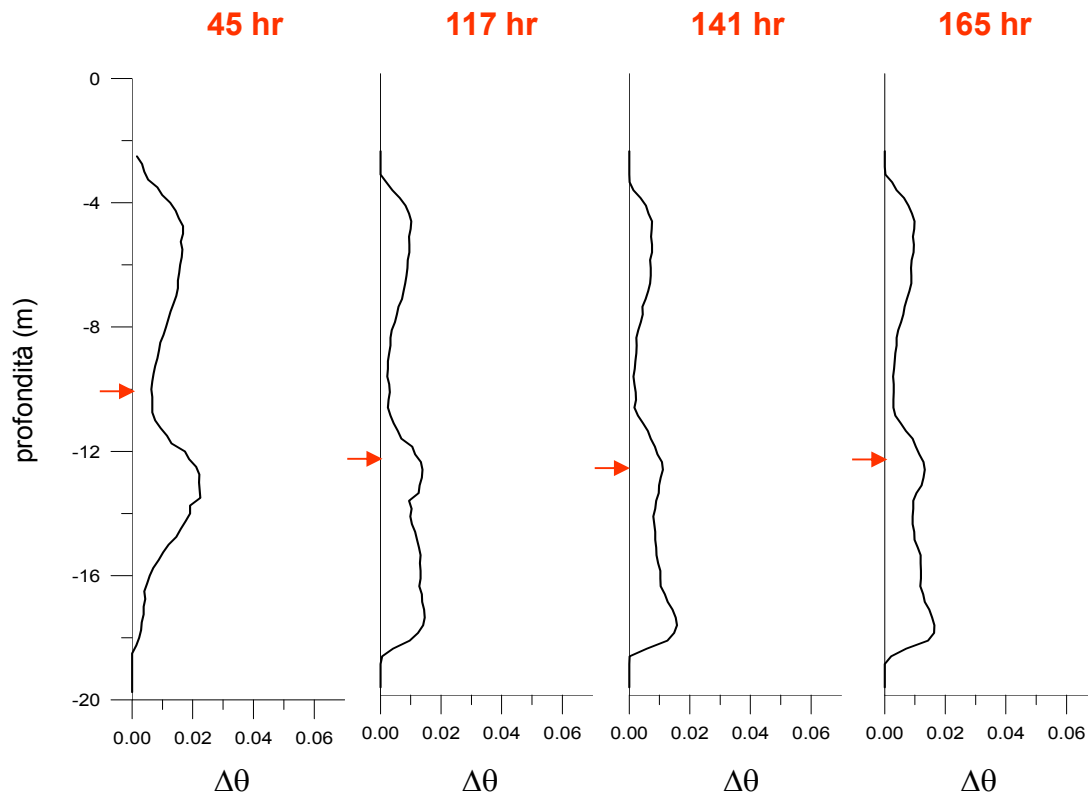
Prima fase di drenaggio



zop GPR



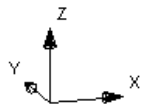
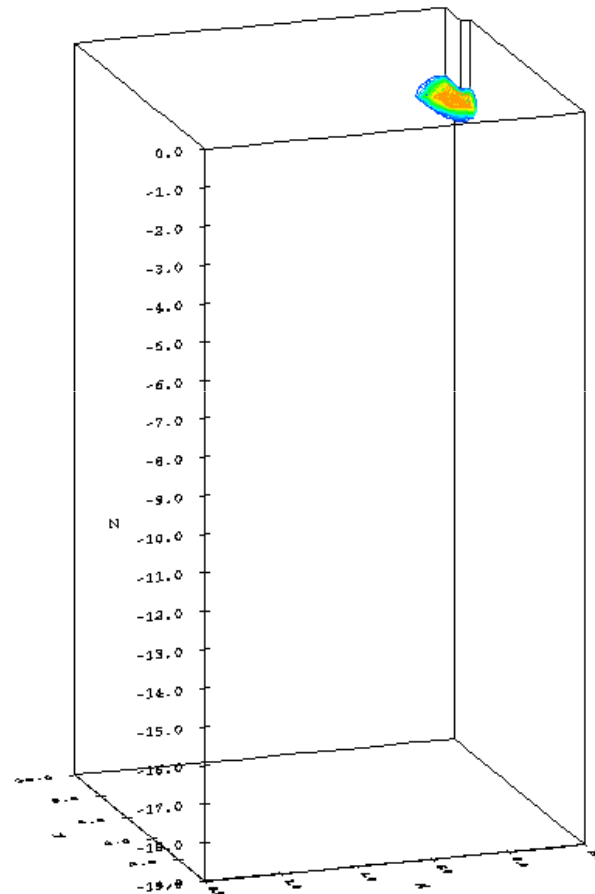
Seconda fase di drenaggio



zop GPR

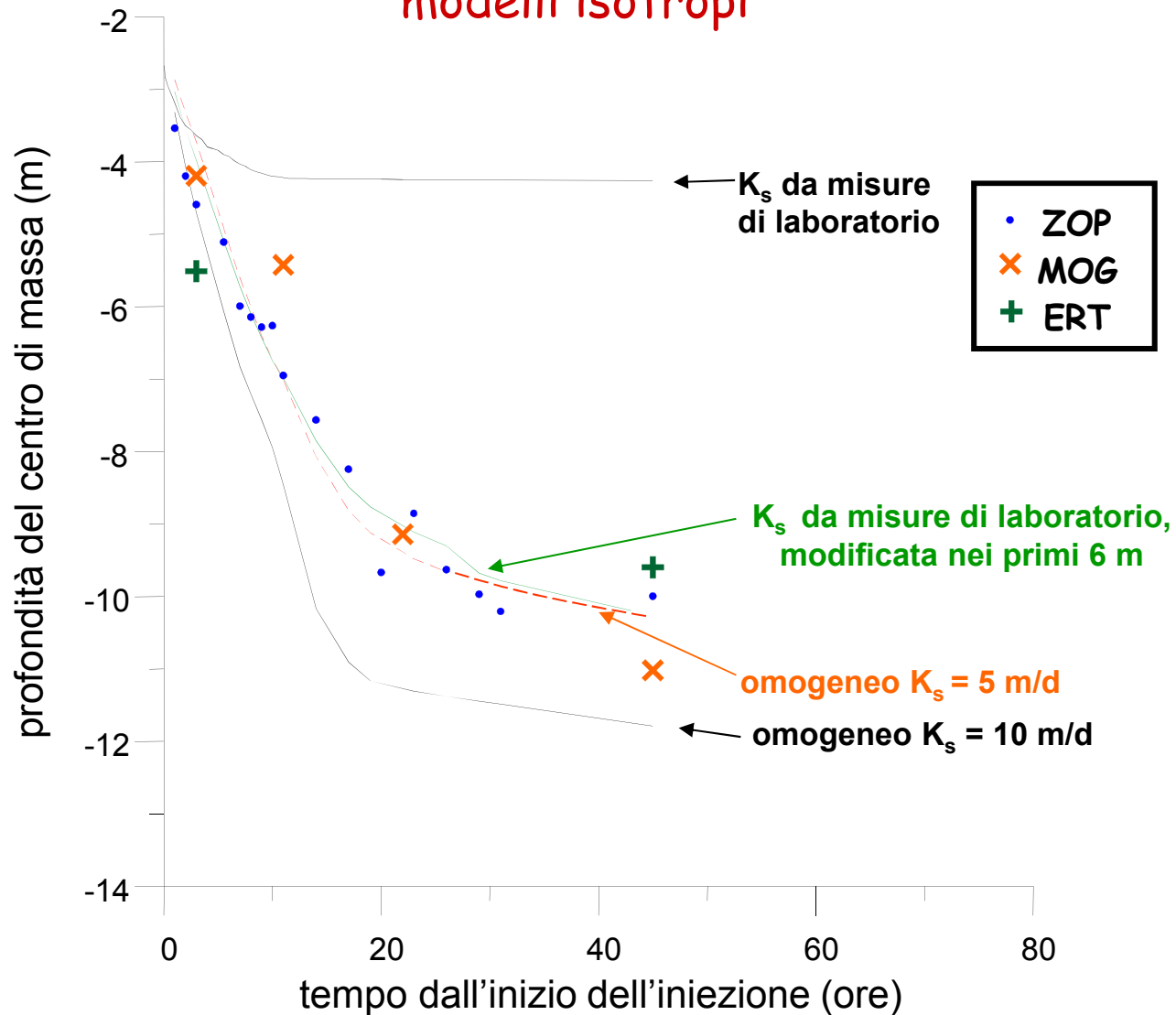


Modellazione 3-D dell' iniezione controllata





Calibrazione del modello sul centro di massa modelli isotropi

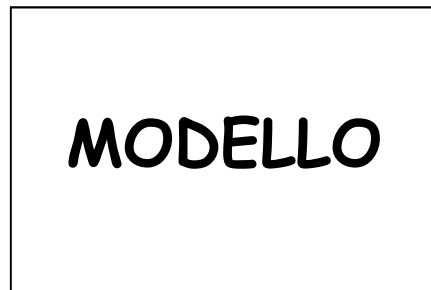




BILANCIO DI MASSA

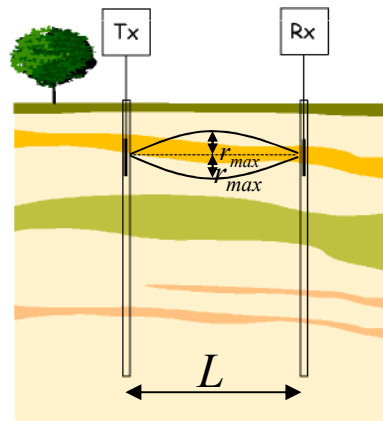
una questione da risolvere

massa d'acqua
iniettata: nota



massa d'acqua
in un certo
volume di controllo

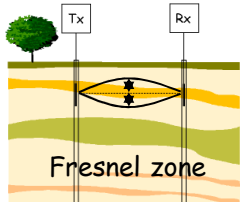
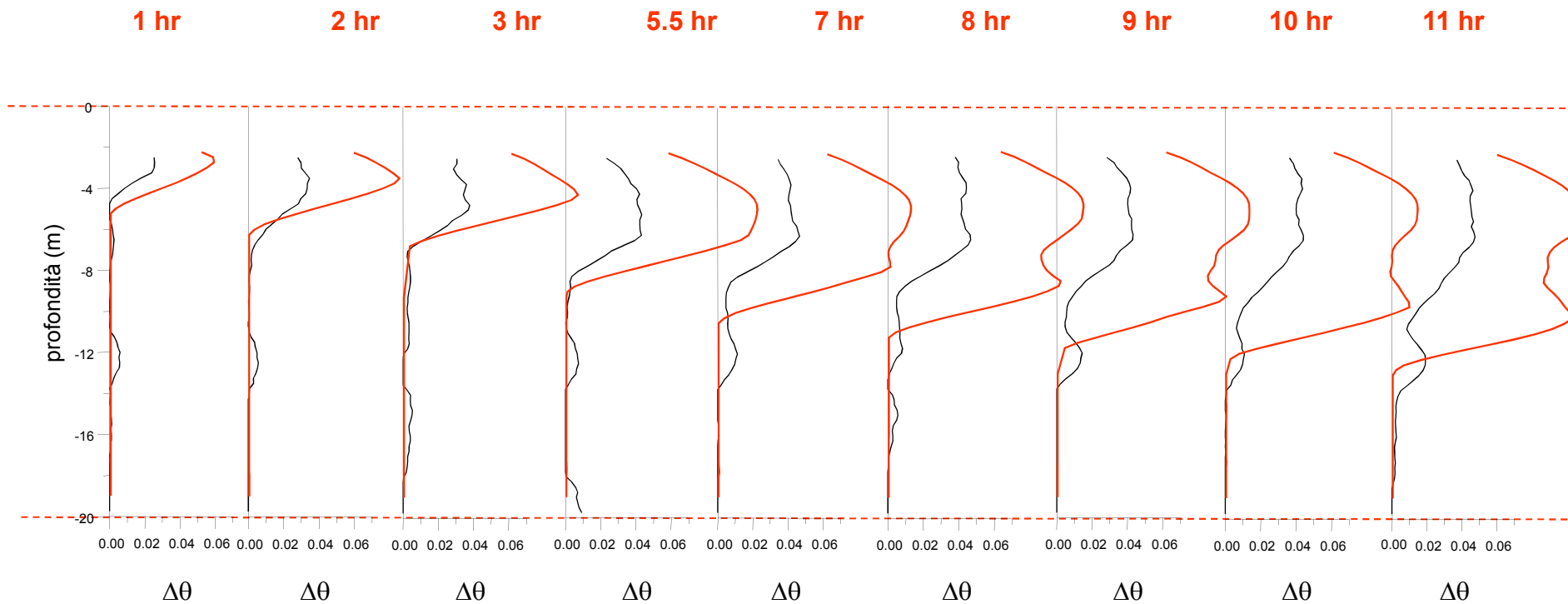
zone di Fresnel



massa d'acqua
in un certo
volume di controllo



Fase di iniezione



misure con ZOP GPR

risultati del modello isotropo con $K_s = 5 \text{ m/d}$



Fase di drenaggio

14 hr

17 hr

20 hr

22 hr

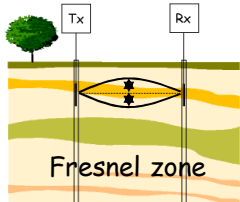
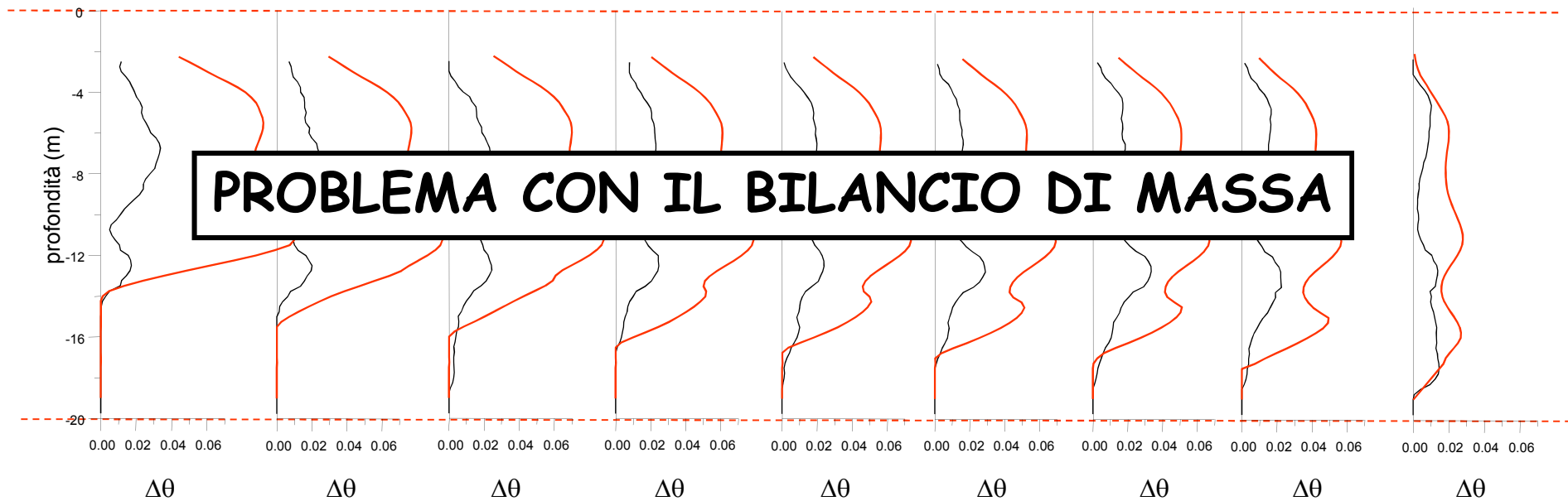
26 hr

29 hr

31 hr

45 hr

117 hr

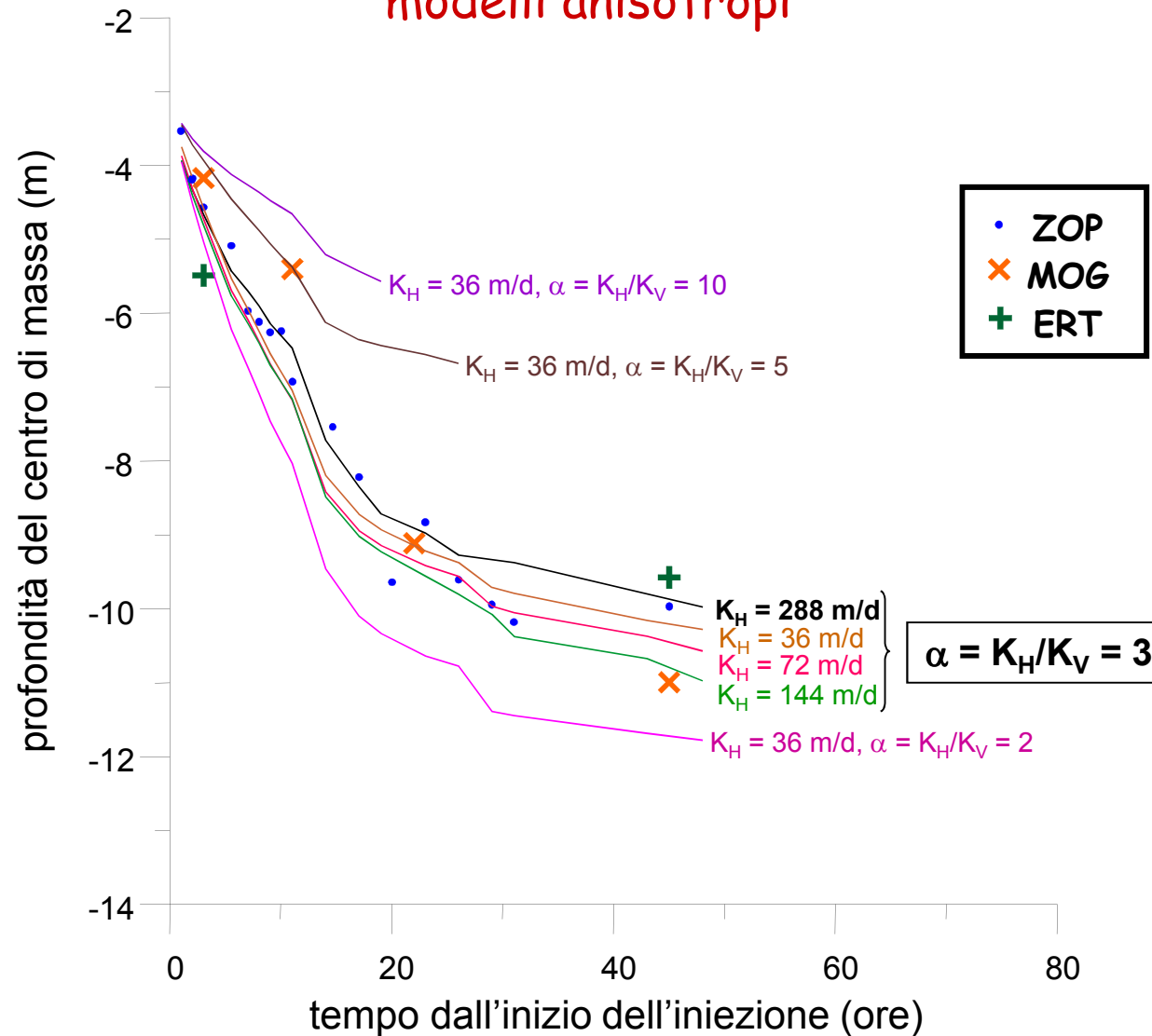


misure con ZOP GPR

risultati del modello isotropo con $K_s = 5 \text{ m/d}$

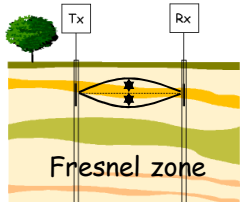
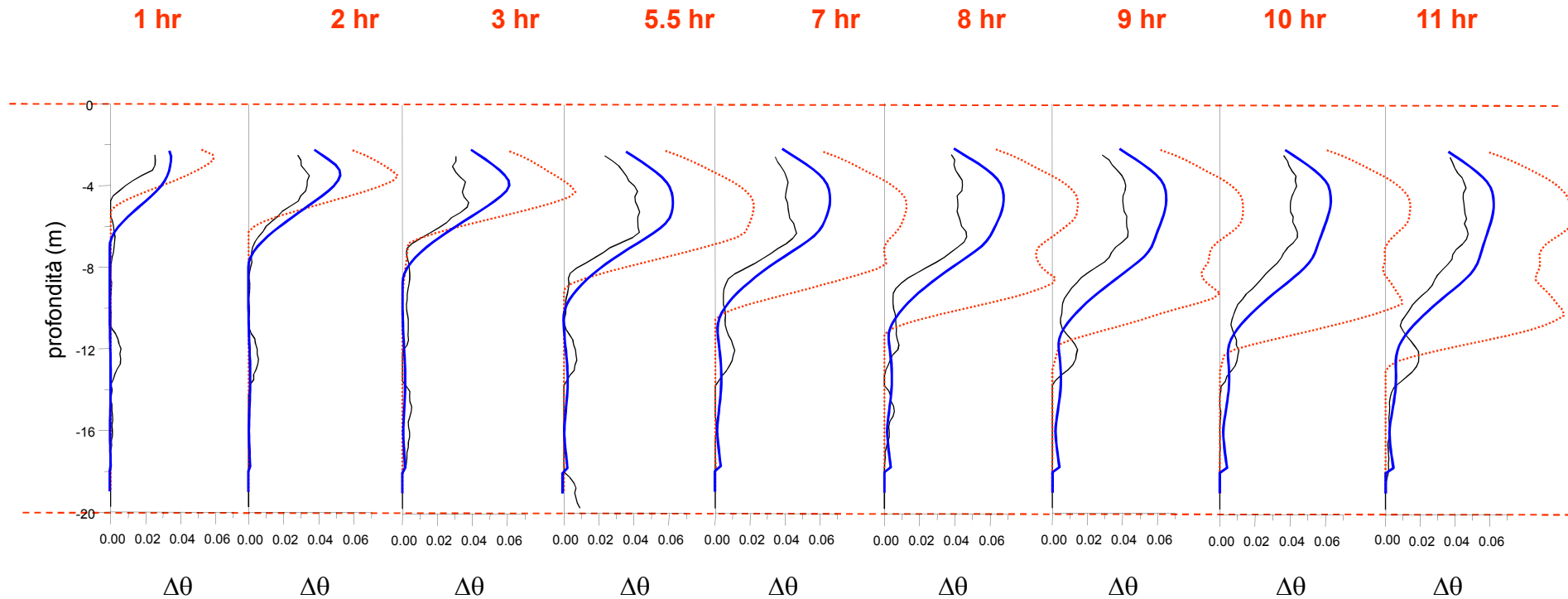


Calibrazione del modello sul centro di massa modelli anisotropi





Fase di iniezione



misure con ZOP GPR

risultati del modello isotropo con $K_s = 5 \text{ m/d}$

risultati del modello anisotropo con $K_{sH} = 288 \text{ m/d}$, $\alpha = K_{sH}/K_{sV} = 3$



Fase di drenaggio

14 hr

17 hr

20 hr

22 hr

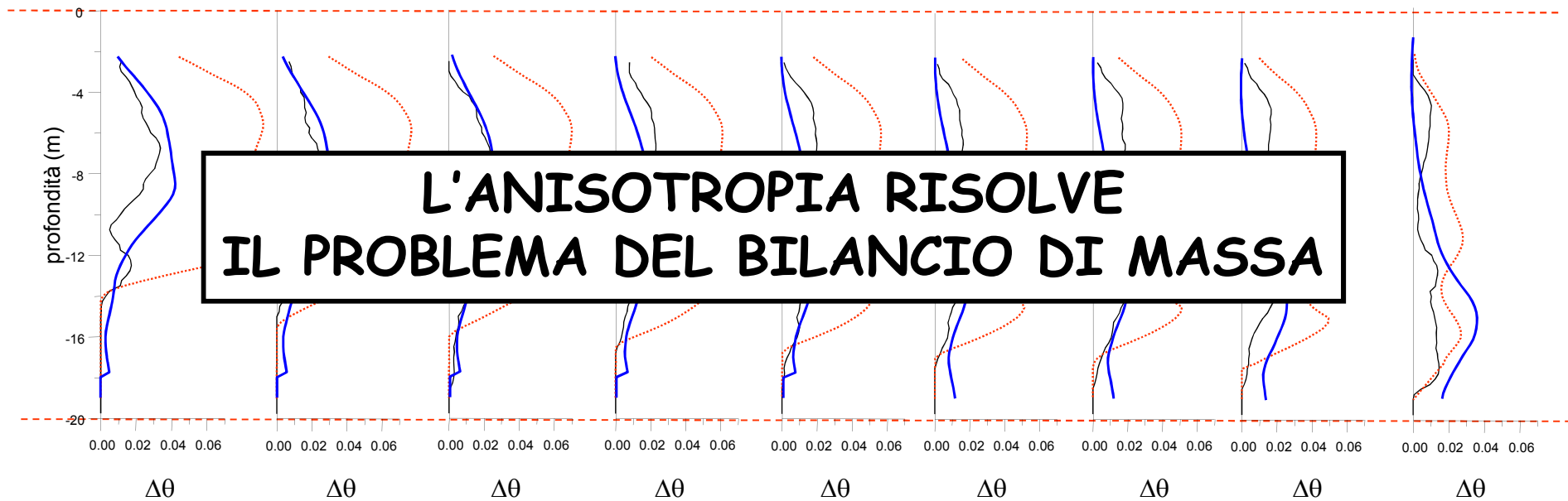
26 hr

29 hr

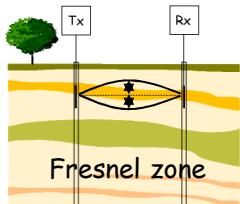
31 hr

45 hr

117 hr



L'ANISOTROPIA RISOLVE IL PROBLEMA DEL BILANCIO DI MASSA



misure con ZOP GPR

risultati del modello isotropo con $K_s = 5 \text{ m/d}$

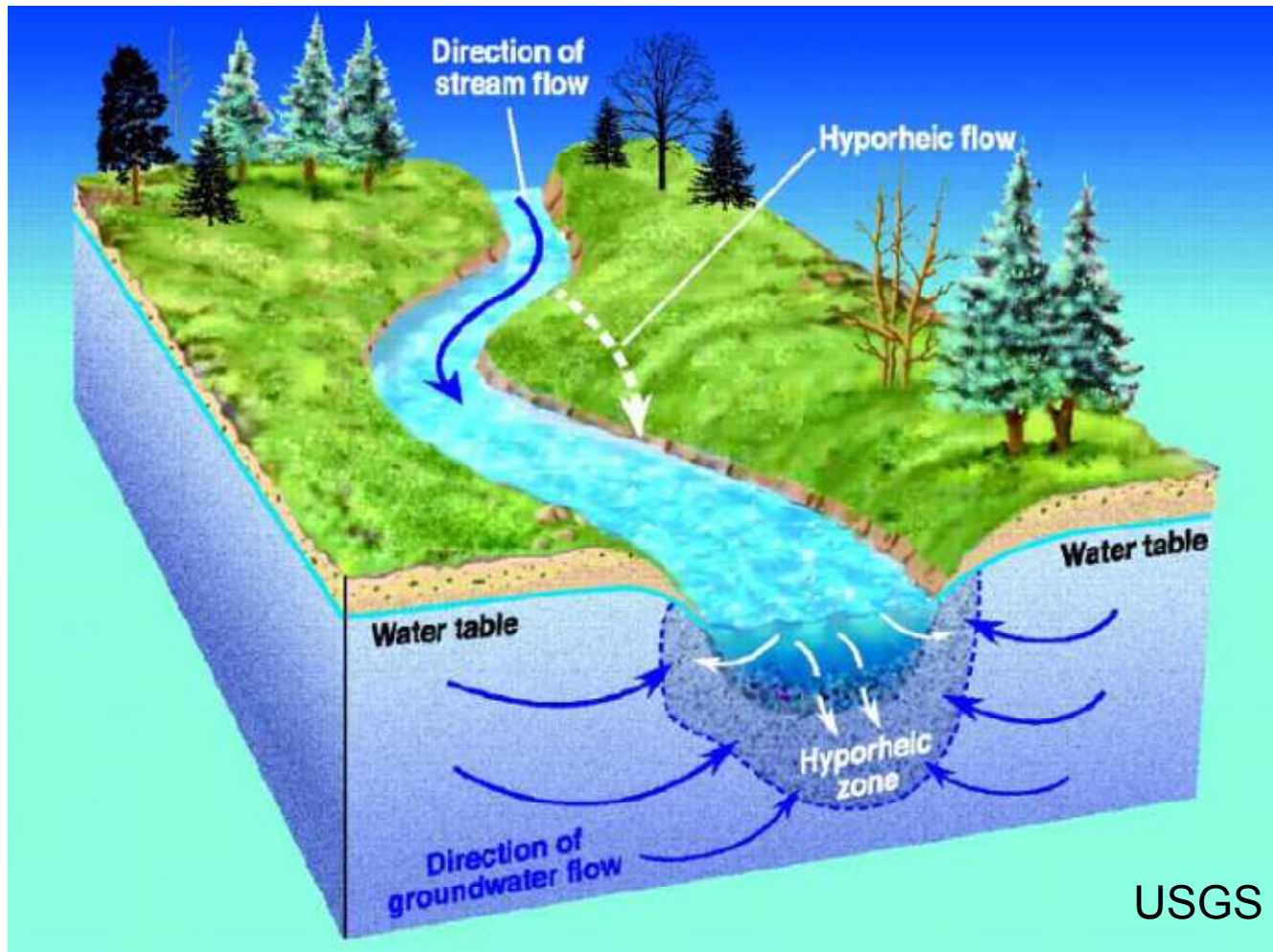
risultati del modello anisotropo con $K_{sH} = 288 \text{ m/d}$, $\alpha = K_{sH}/K_{sV} = 3$







The hyporheic zone





1. The test site and aims



- 'Val di Sole' valley, Trentino, Central Alps, Italy
- Test site located at 1500 m amsl
- Catchment of 78.5 km², from the 'Presena' Glacier (2700-3000 amsl)
- Reinforced dike river 'Vermigliana' (flow rate of 0.5 - 4 m³/s)

FP7 Project



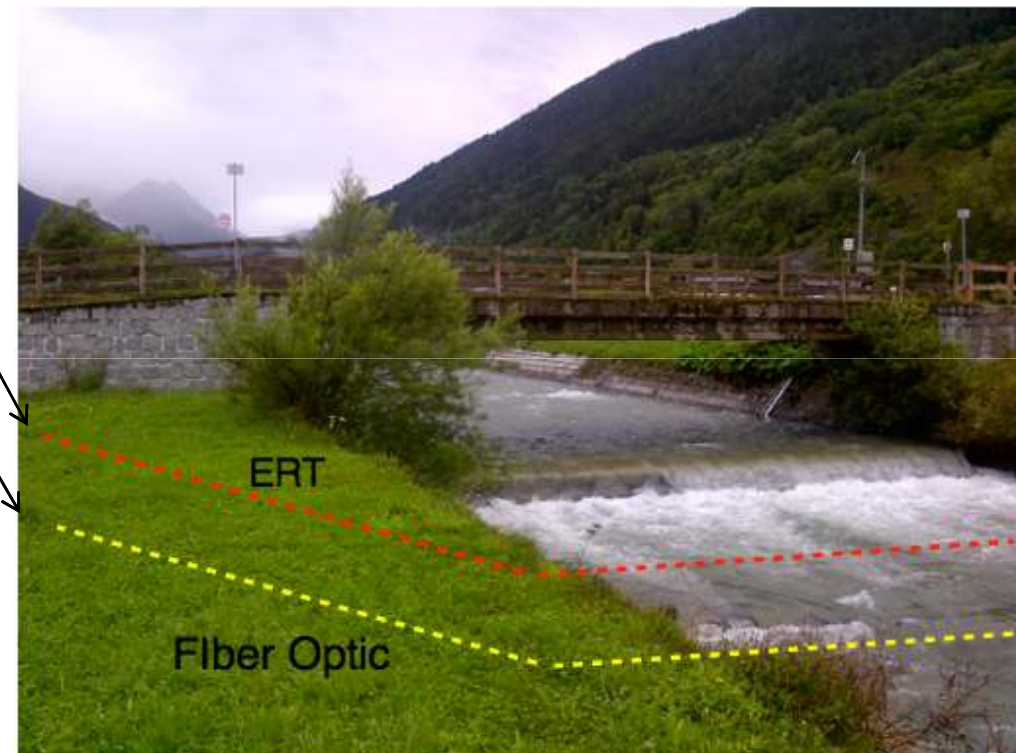


1. The test site and aims

Focusing on the Hyporheic Zone

Oriented Drilling boreholes:

- ERT cable 5m under river's bed
- Hybrid FIBER OPTIC parallel to the ERT cable





1. The test site and aims

Electrical Resistivity Tomography (ERT)

In hole deployment

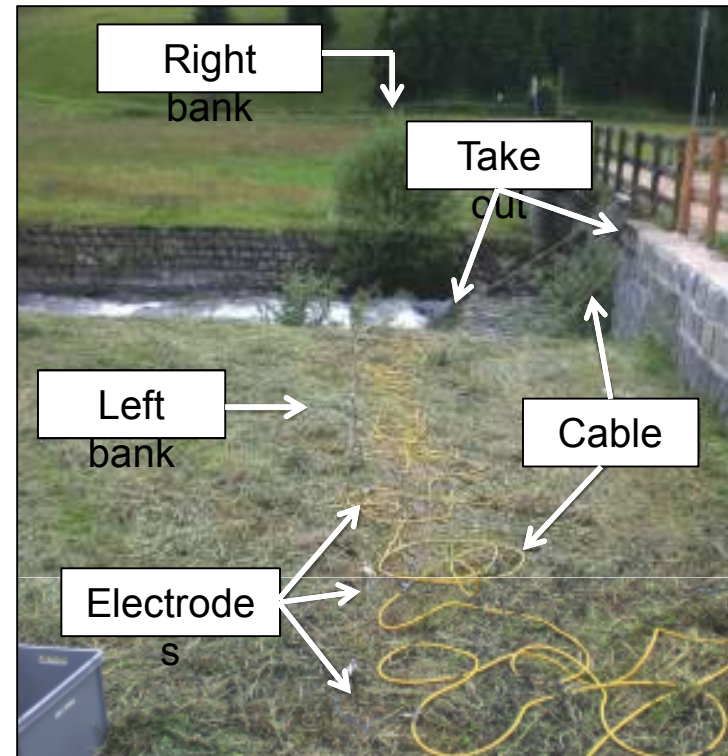
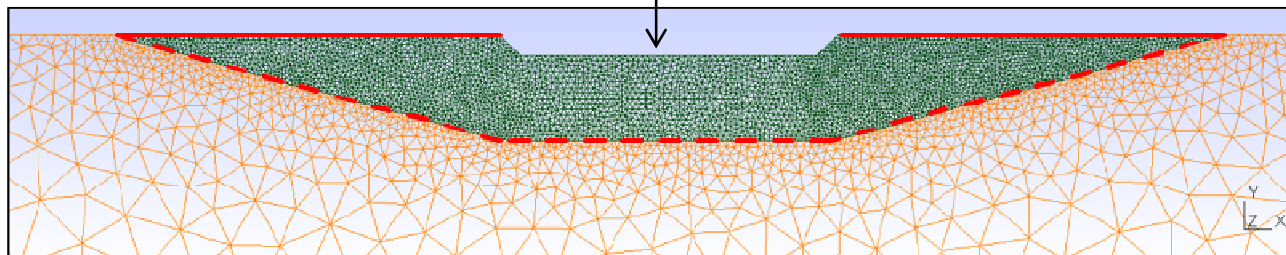
- 48 brass electrodes
 - spacing 1m

=====

Superficial deployment

- 24 stainless steel electrodes
 - spacing 1m

Vermigliana creek



72 ch. dipole-dipole skip 0 configuration, Syscal Pro resistivity meter





1. The test site and aims

Distributed Temperature Sensing (DTS)

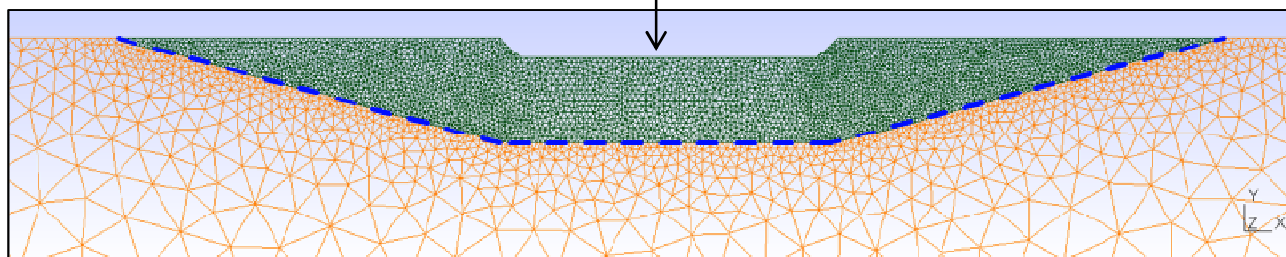


In hole deployment

- double-ended fiber-optic
 - 1 m resolution
- (heating power copper wire)



Vermigliana creek



AP Sensing N43866A Temperature Sensing (“Raman effect”)

G. Cassiani - ERT and DTS time-lapse monitoring of an alpine river hyporheic zone

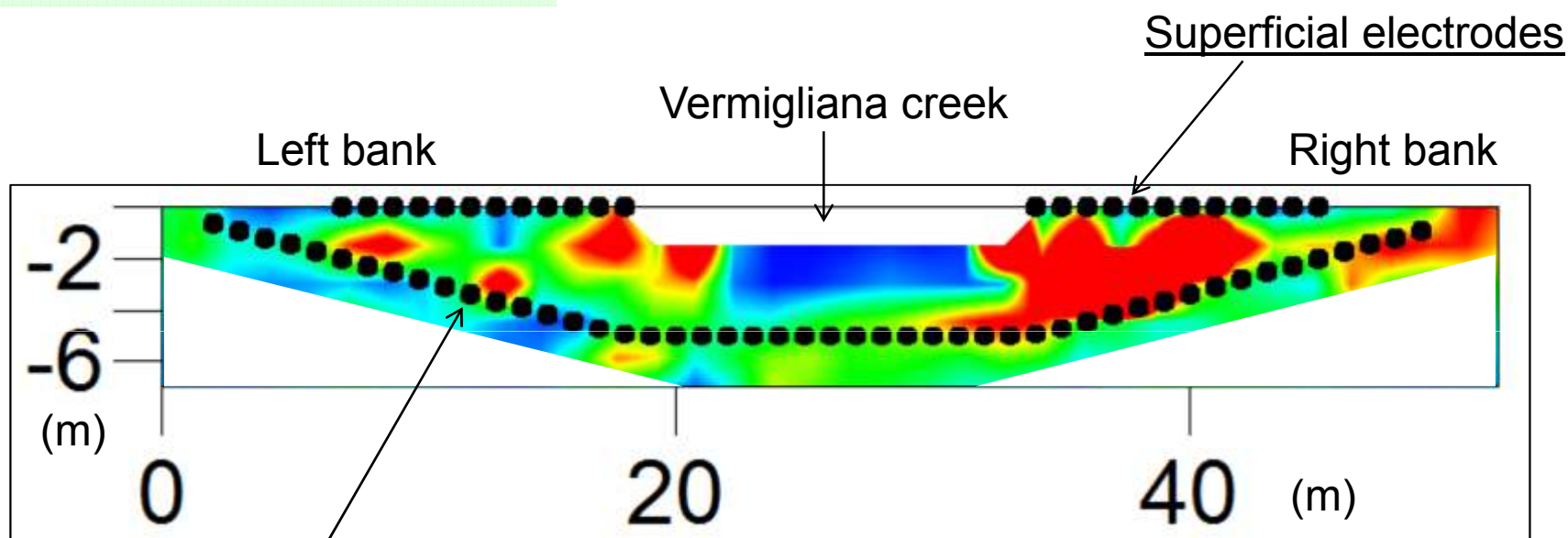




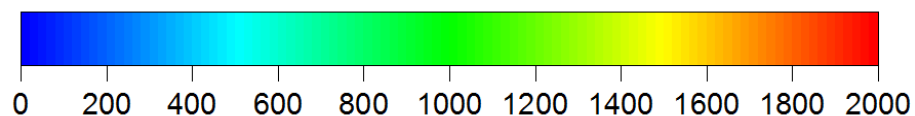
ERT example: Absolute cross-section

State of the domain at the survey time

R2, version 2.7a (Binley, 2013)



Resistivity (Ωm)

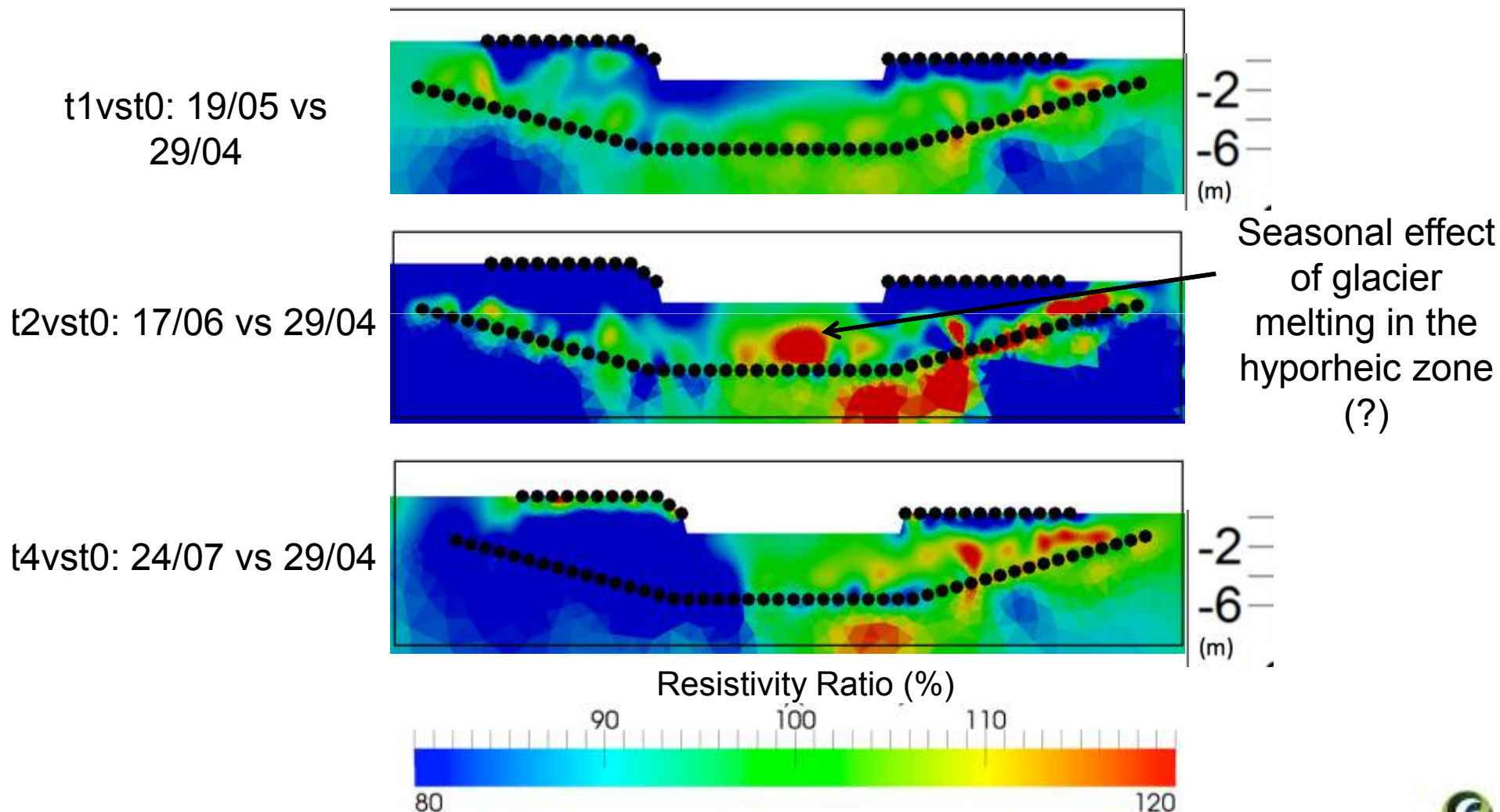




2. Time-lapse ERT results **SEASON 2015**

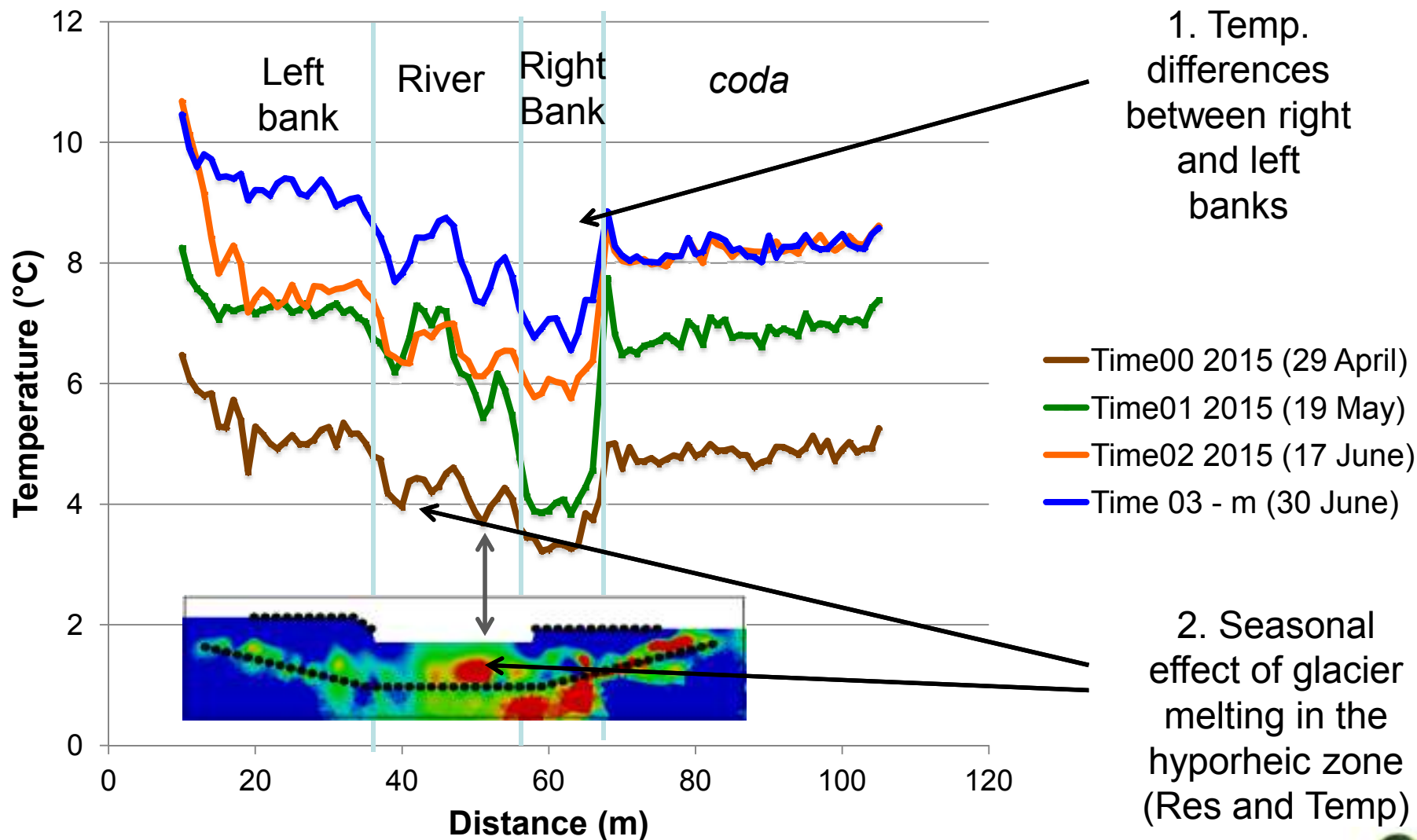
R2 Code, Binley 2014

$$\text{Res. Ratio} = (R_t / R_0) * R_{ohm}$$





3. Distributed Temperature Sensing monitoring **SEASON 2015**



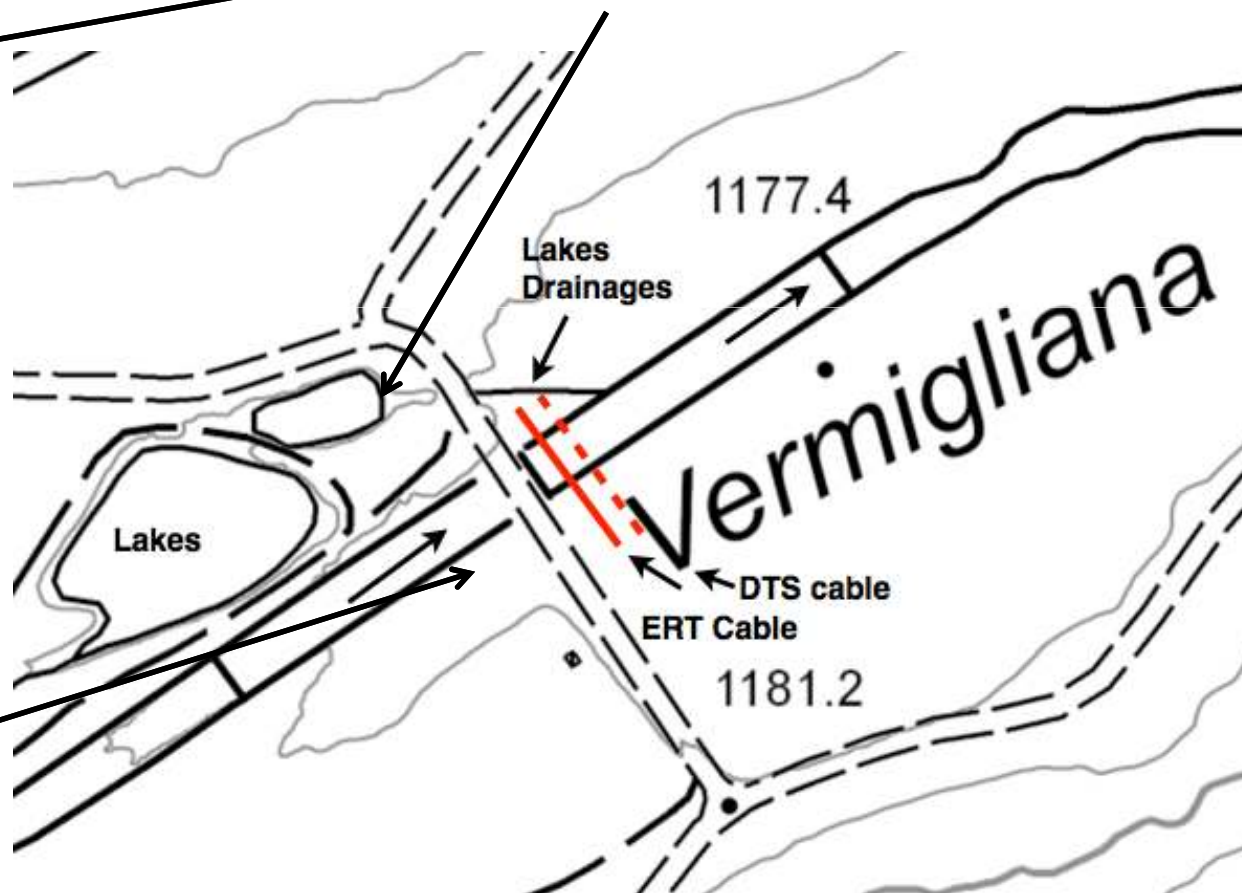


2. Time-lapse DTS results

1. Temperature differences between right and left banks



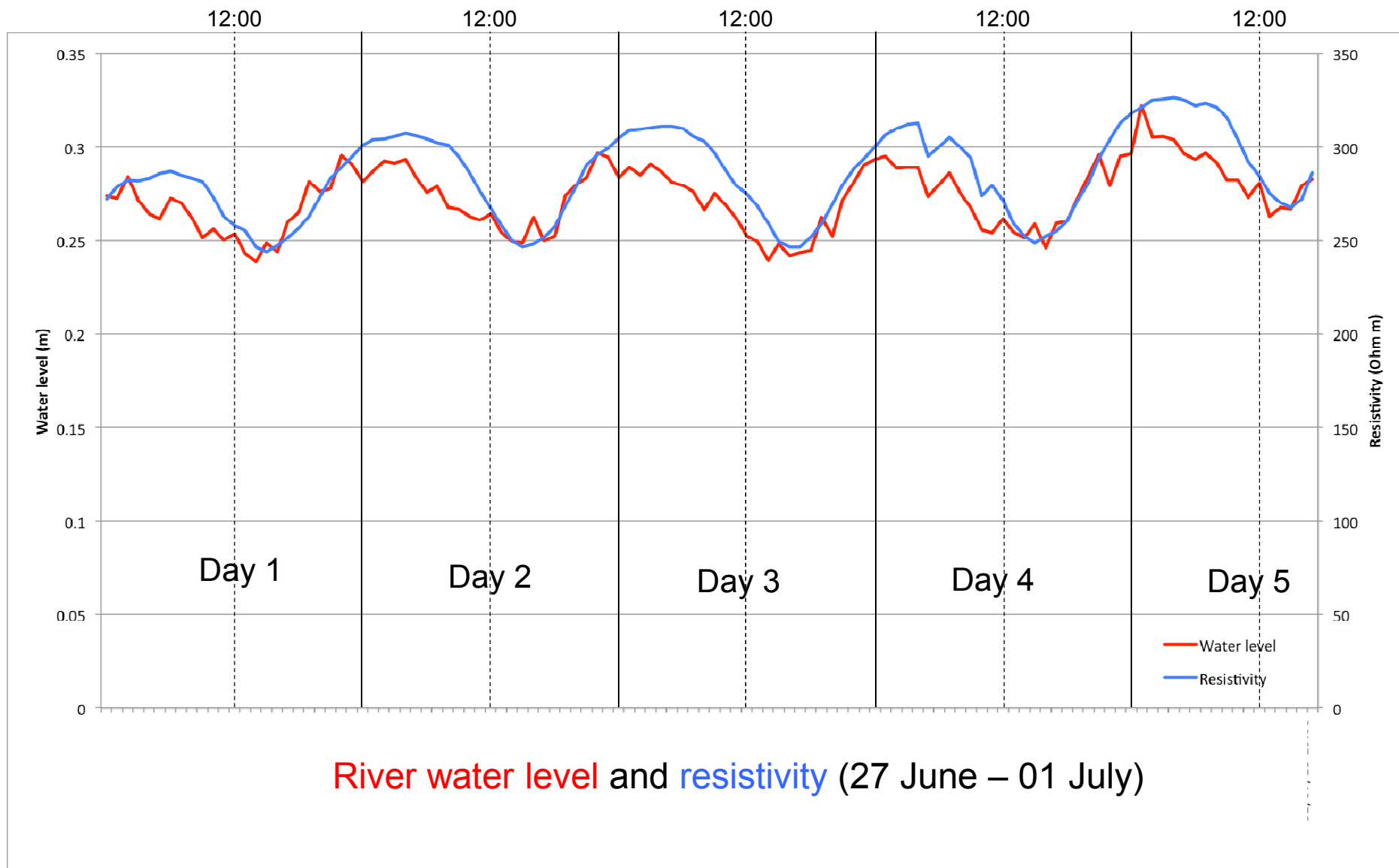
Lakes drainage on the left side



Right side more influenced by glacial outflows

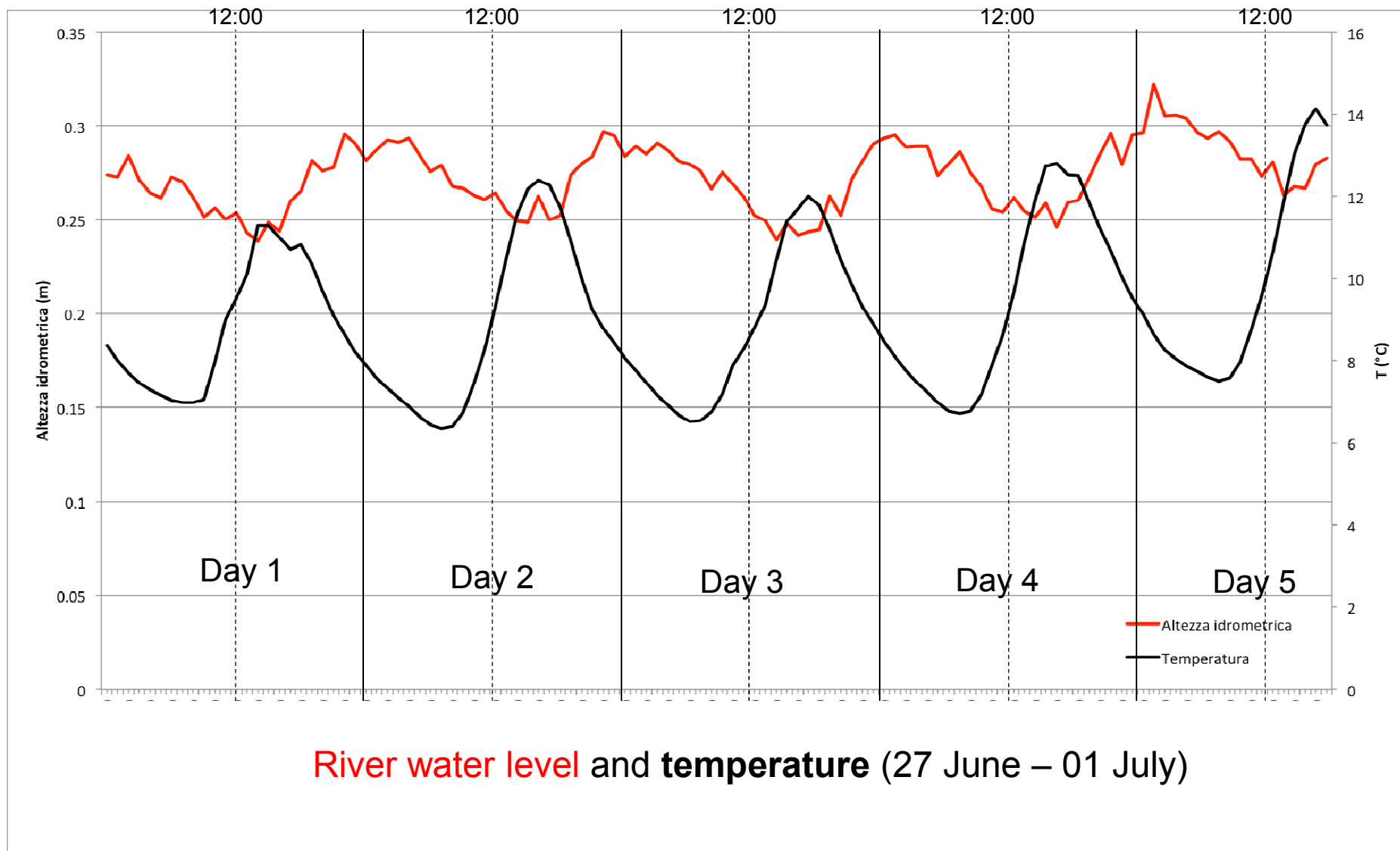


4. Short Term monitoring results 30/06/2015 -01/07/2015

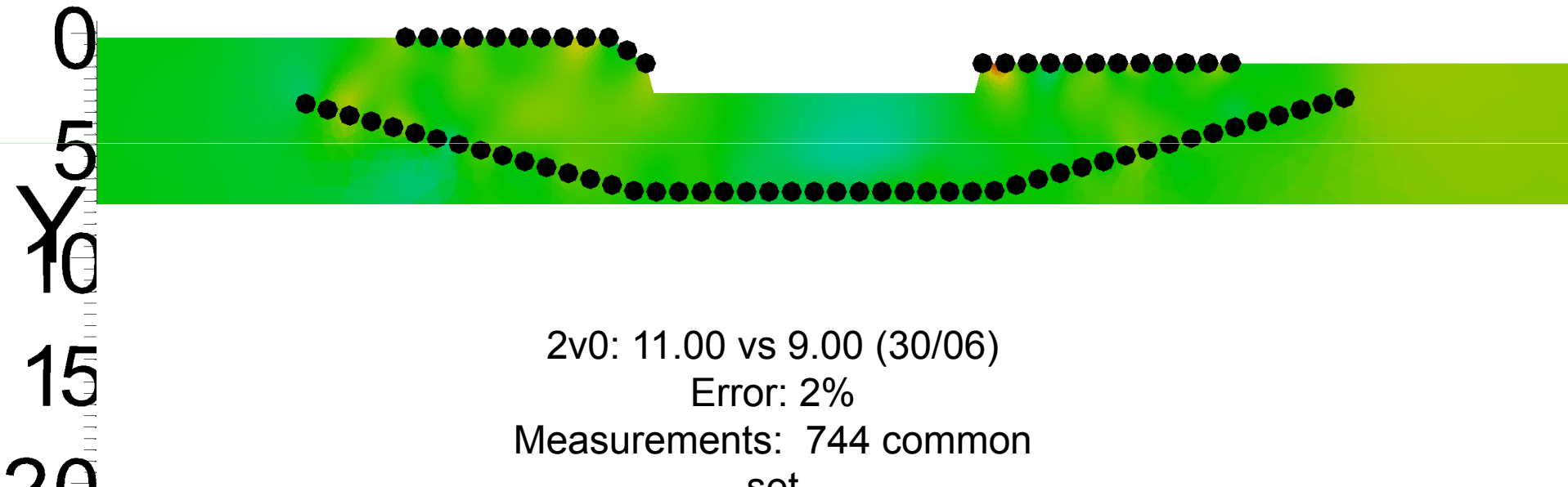
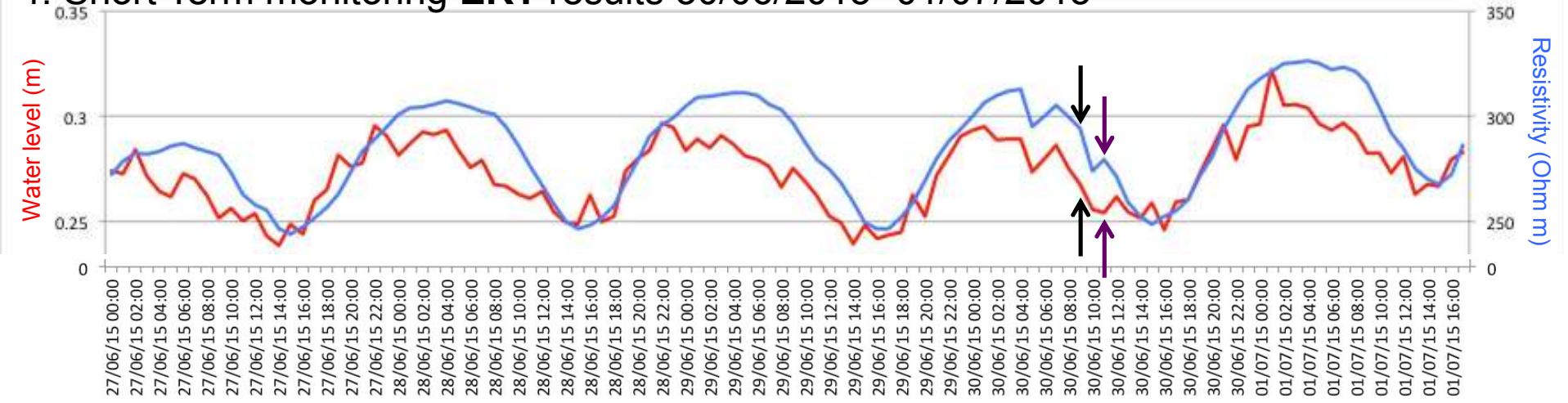




4. Short Term monitoring results 30/06/2015 -01/07/2015

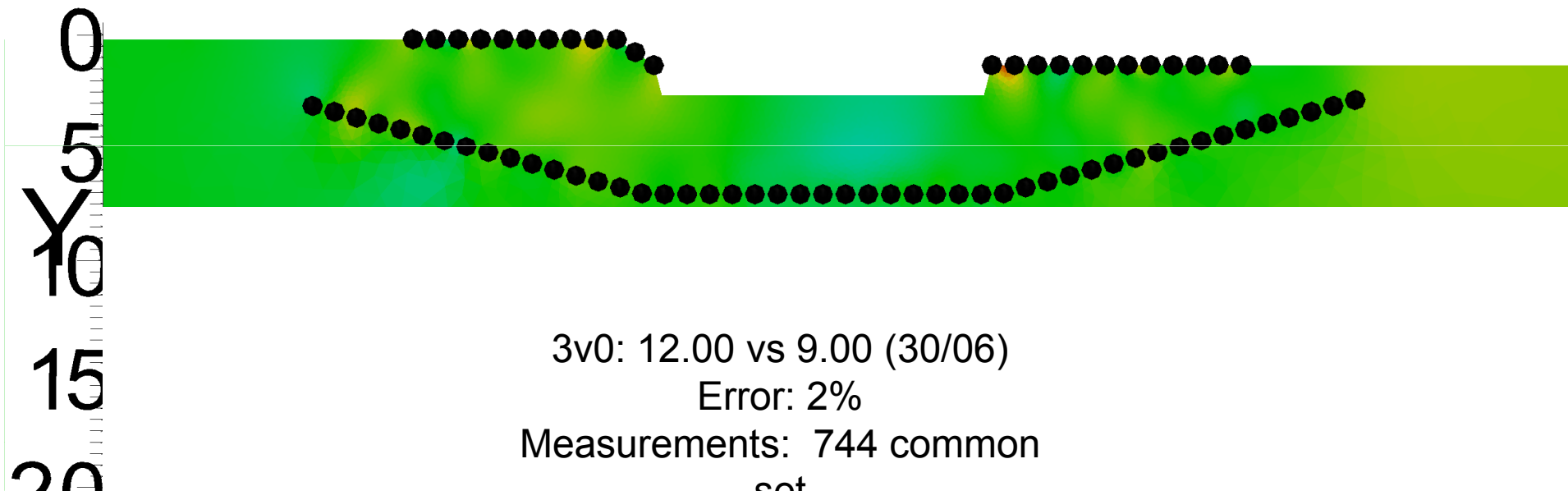
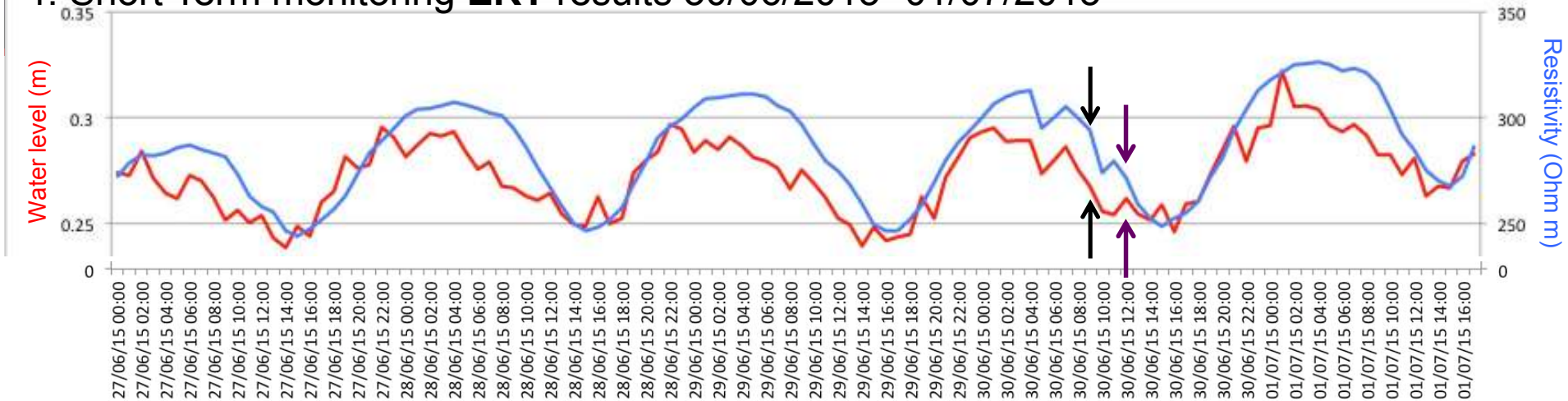


River water level and temperature (27 June – 01 July)



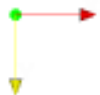
a_wgt and b_wgt are too high

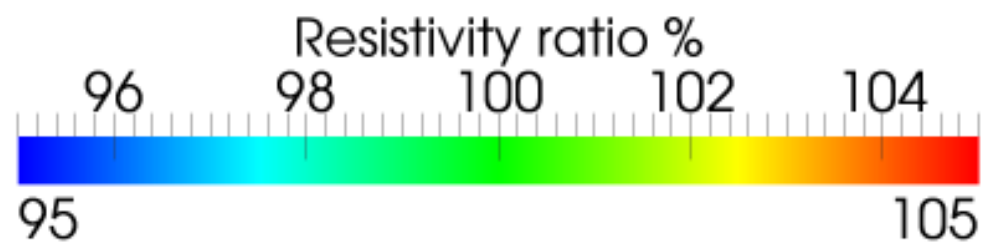
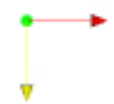
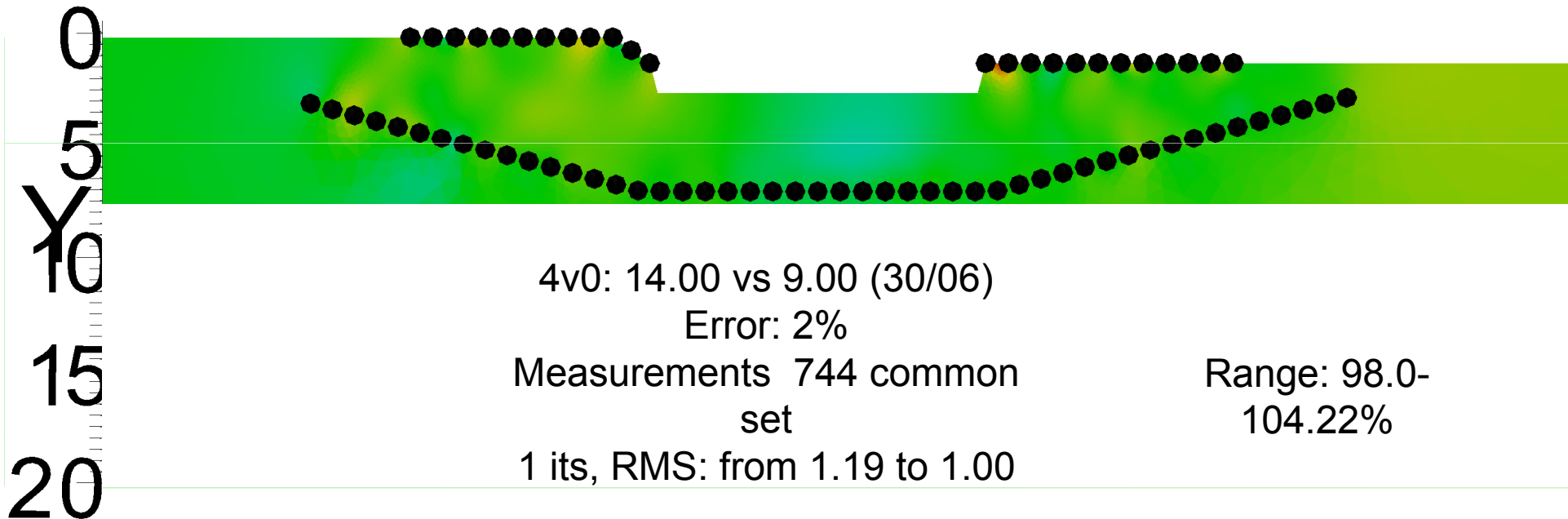
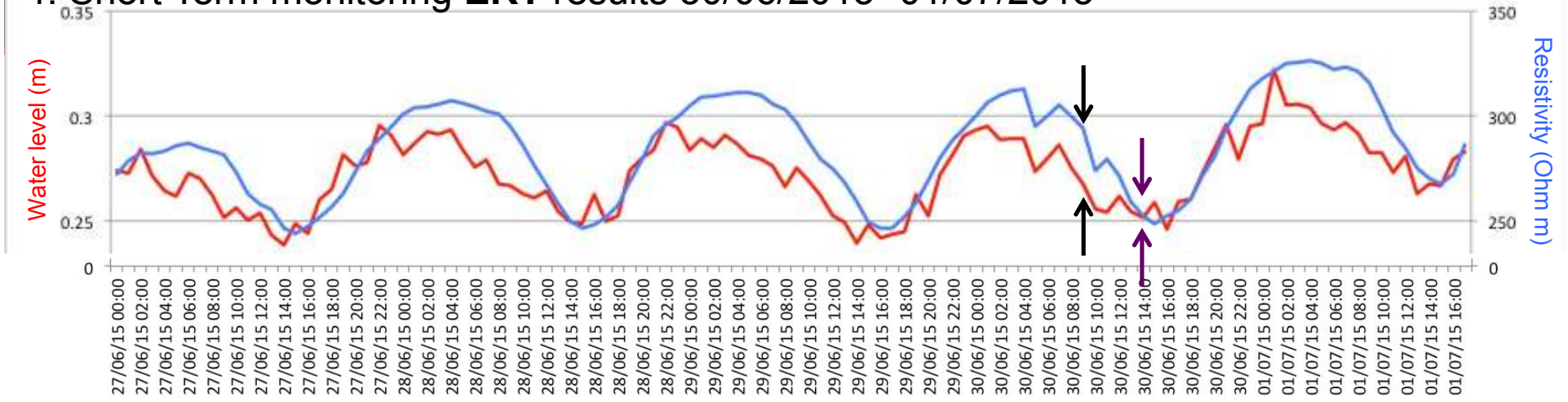


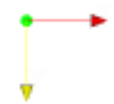
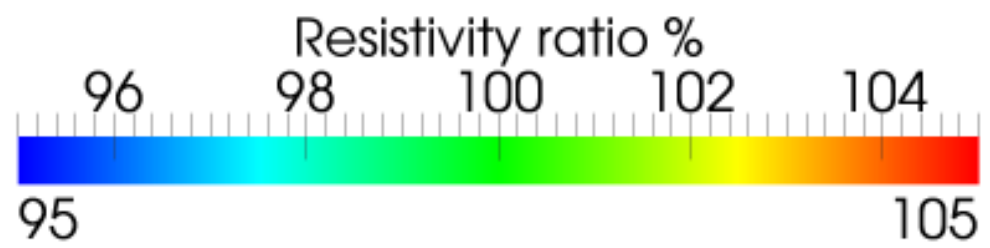
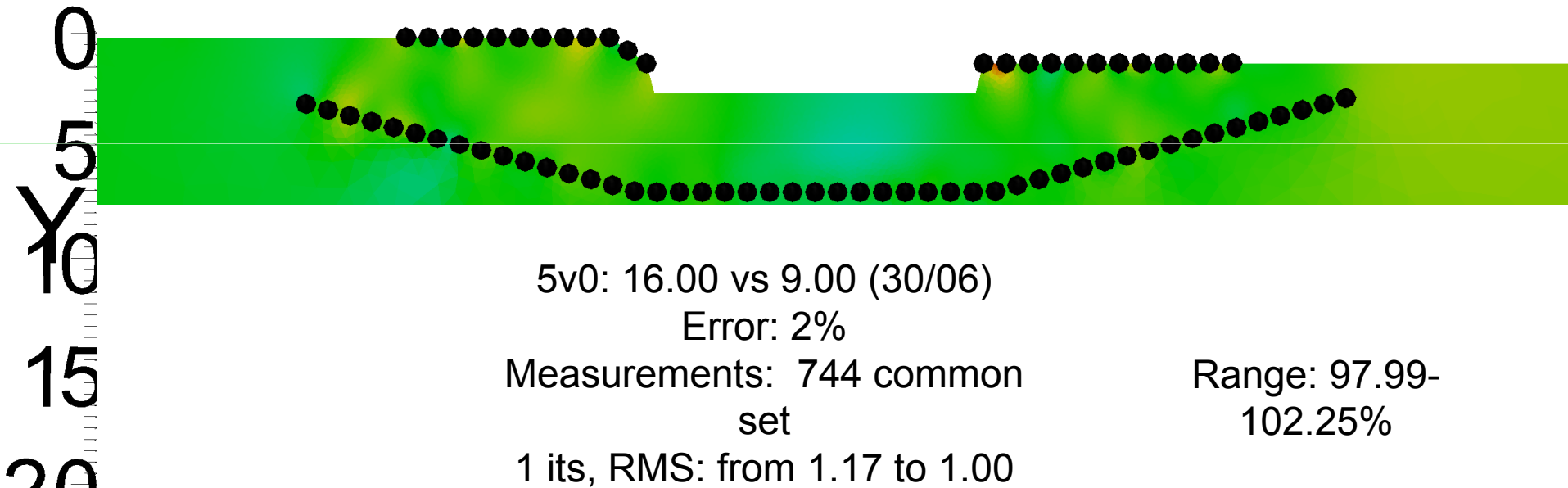
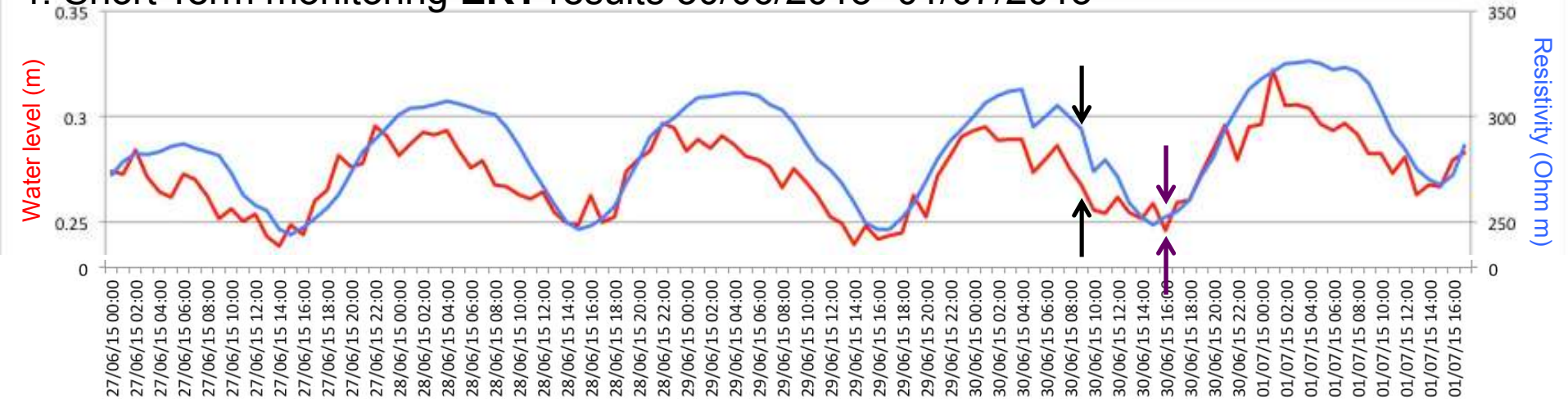


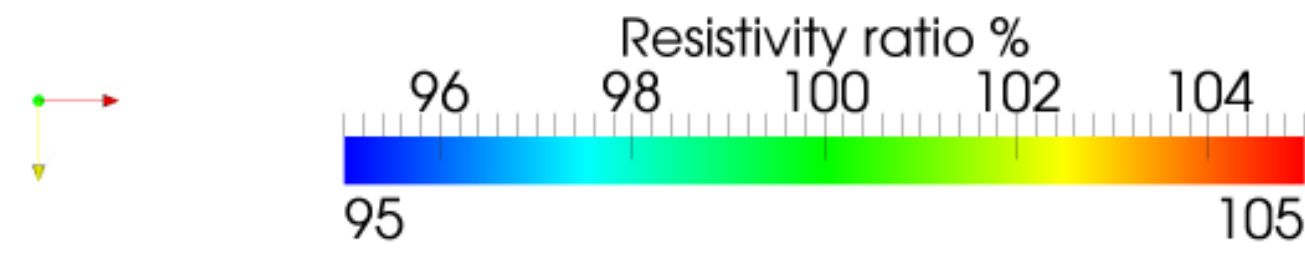
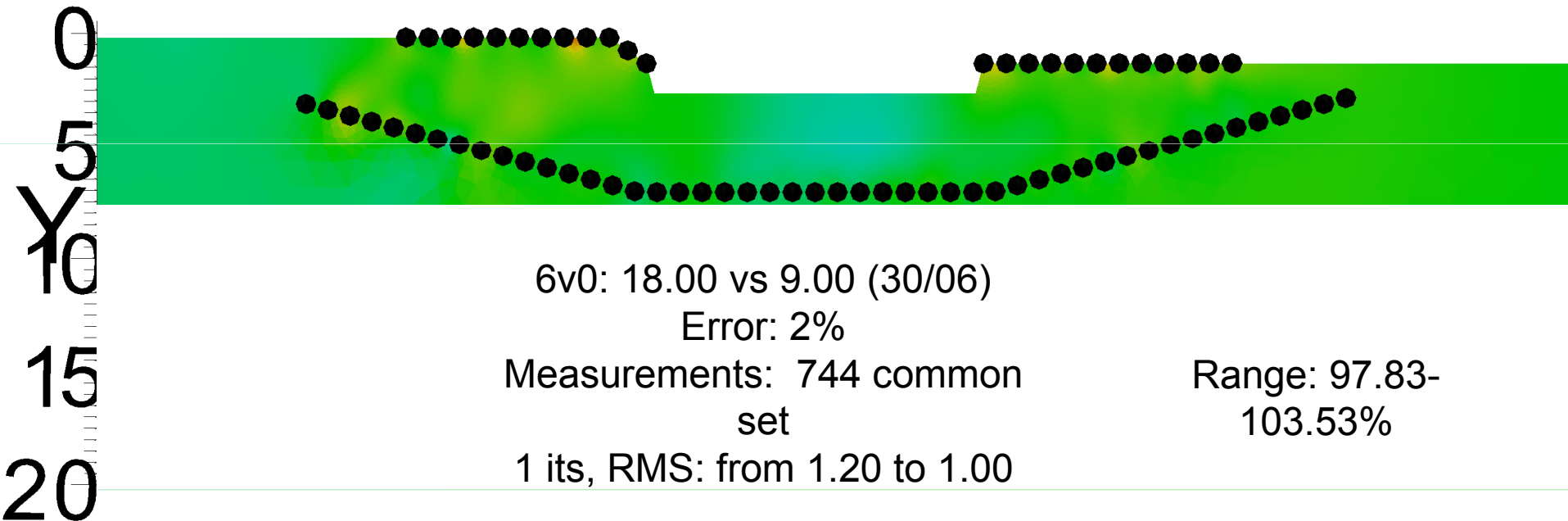
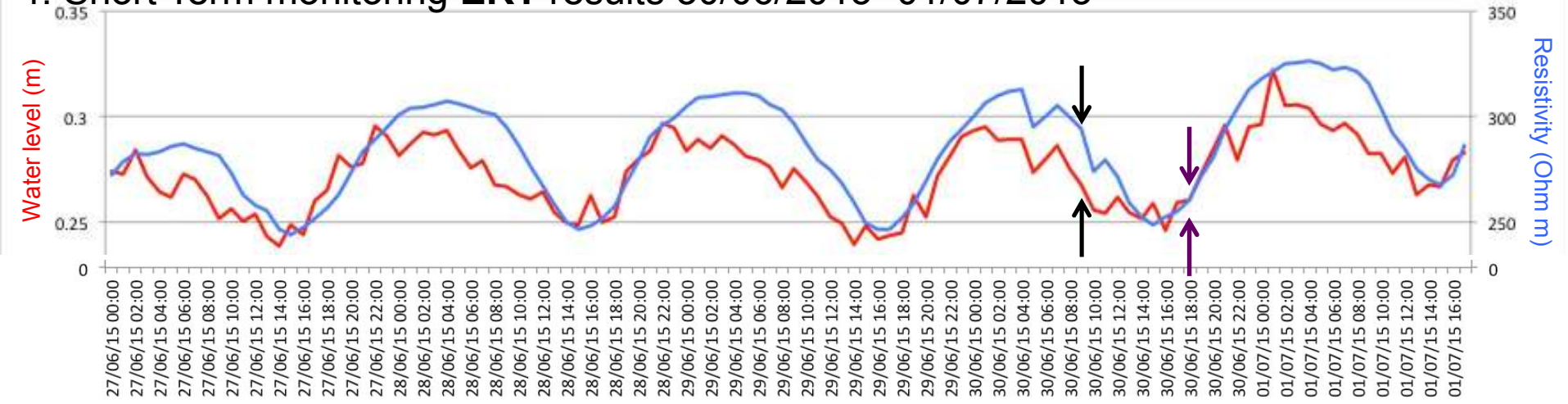
a_wgt and b_wgt are too high

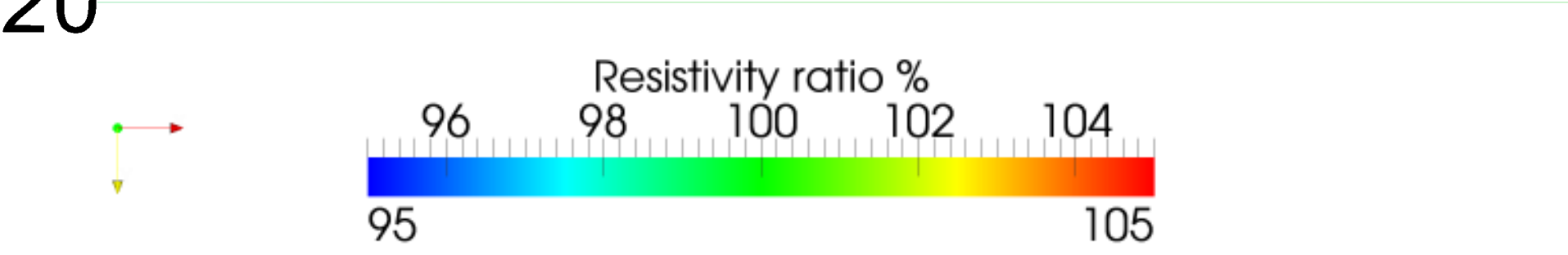
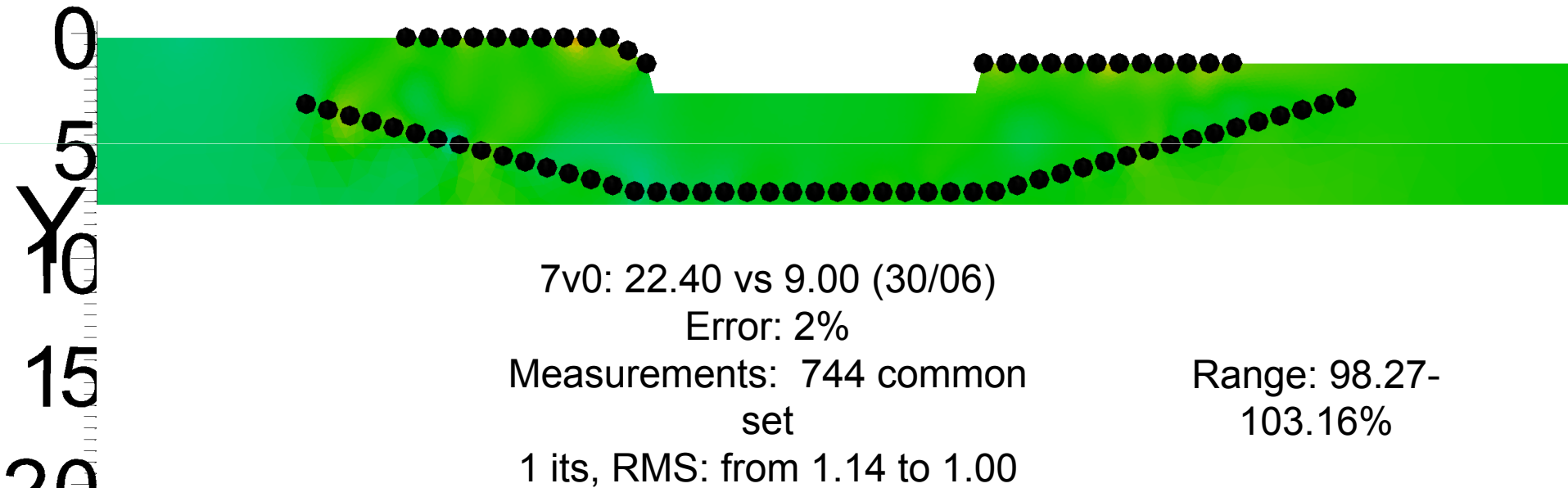
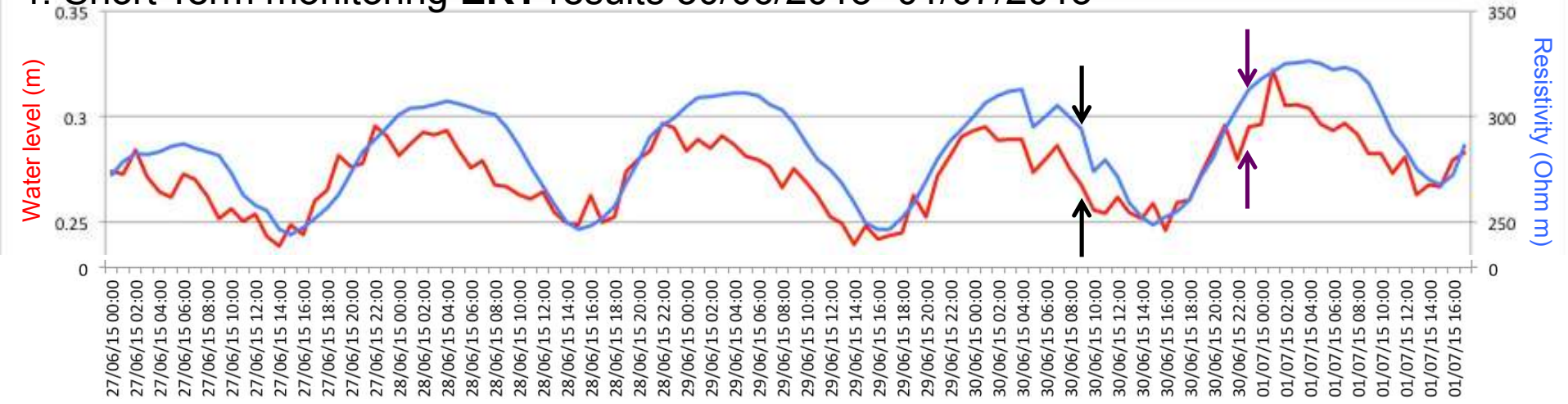
Resistivity ratio %

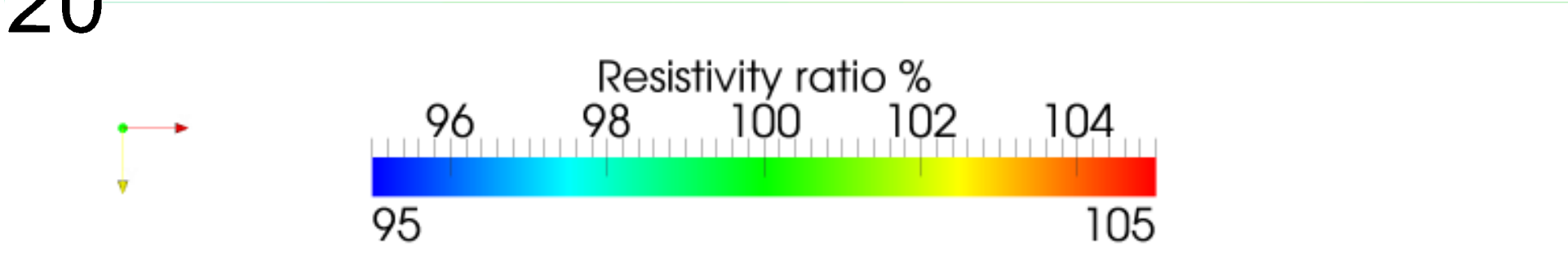
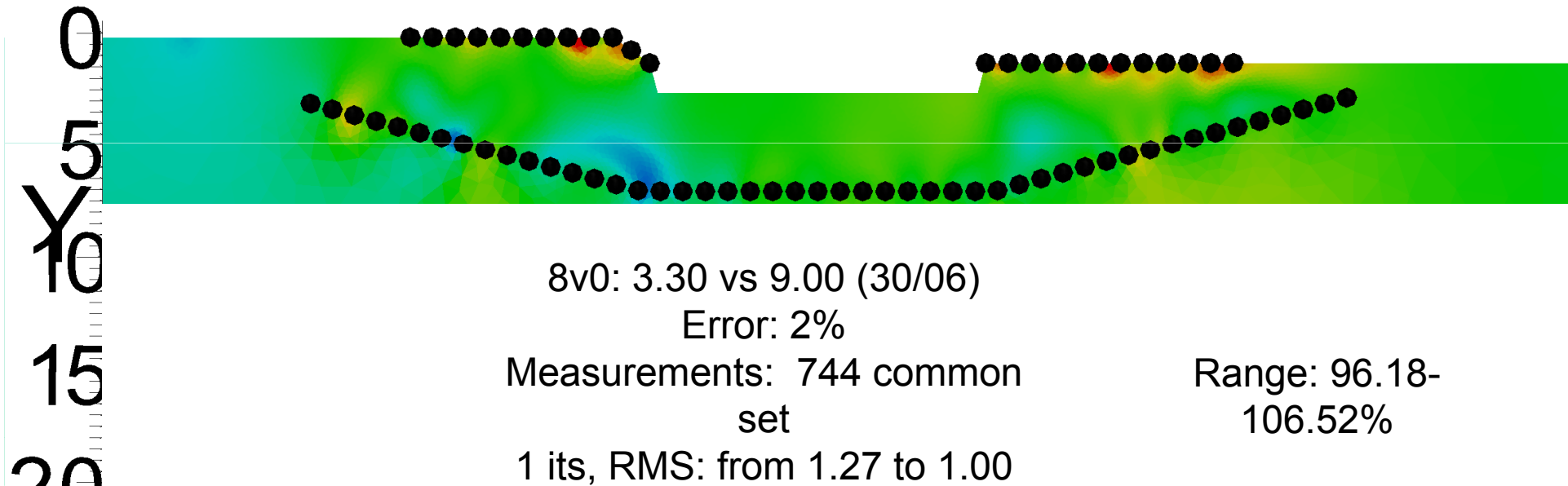
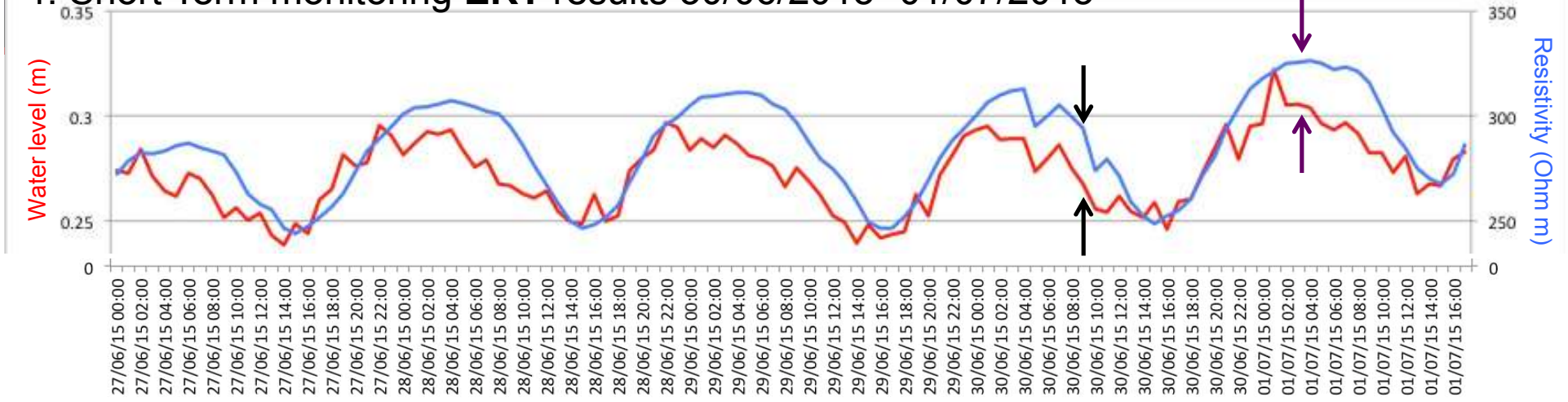


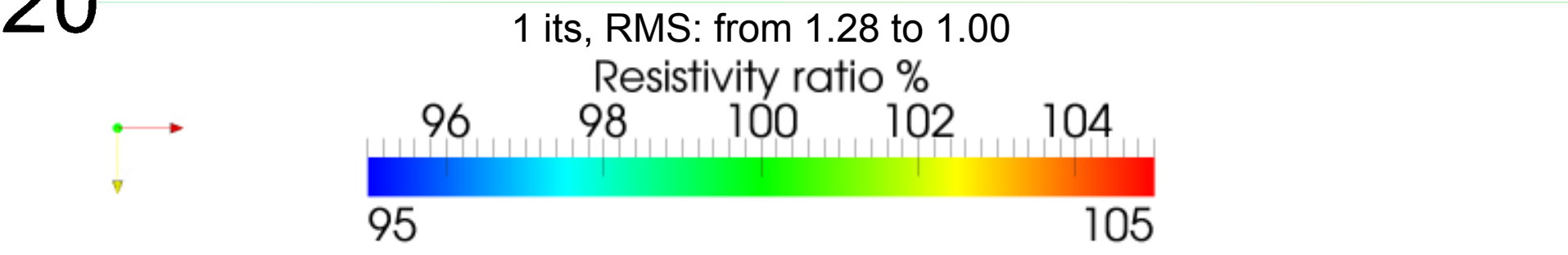
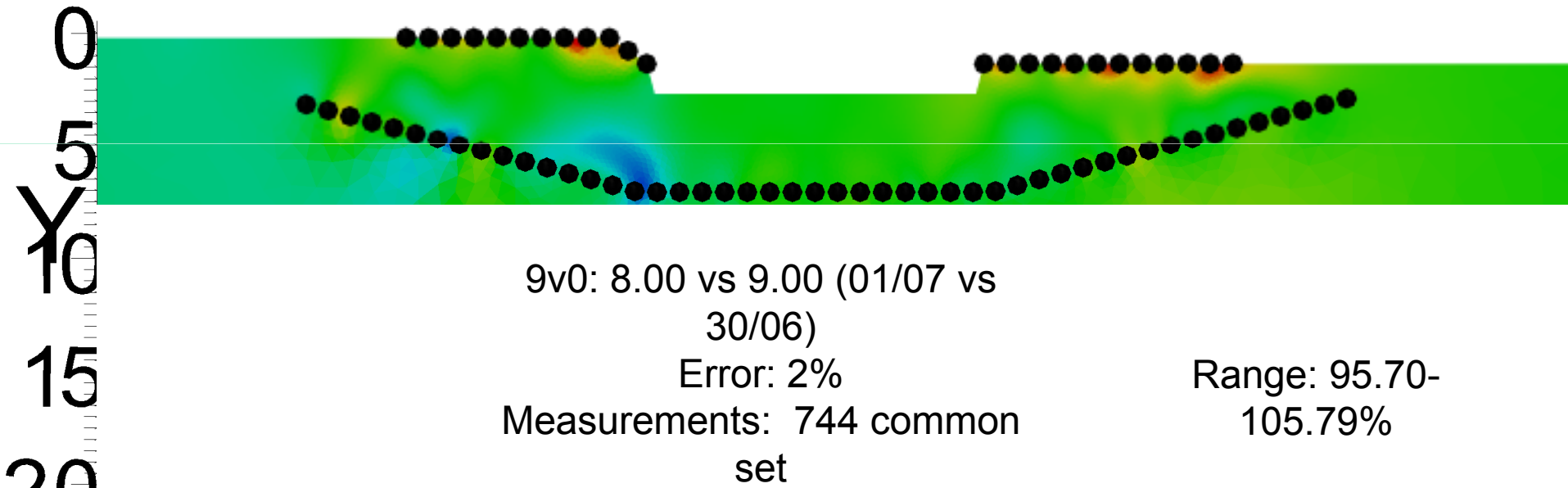
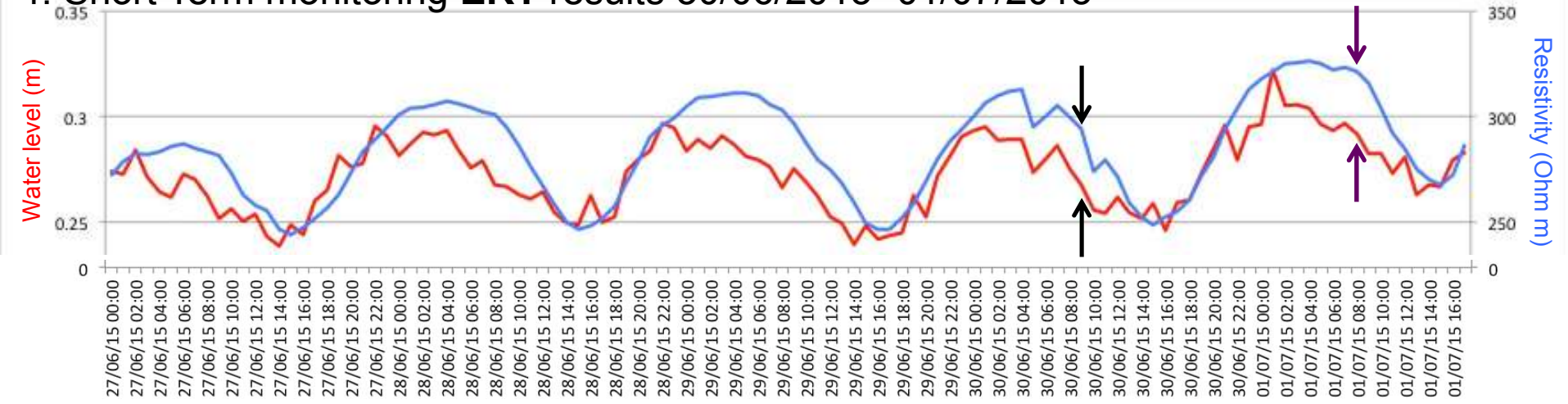


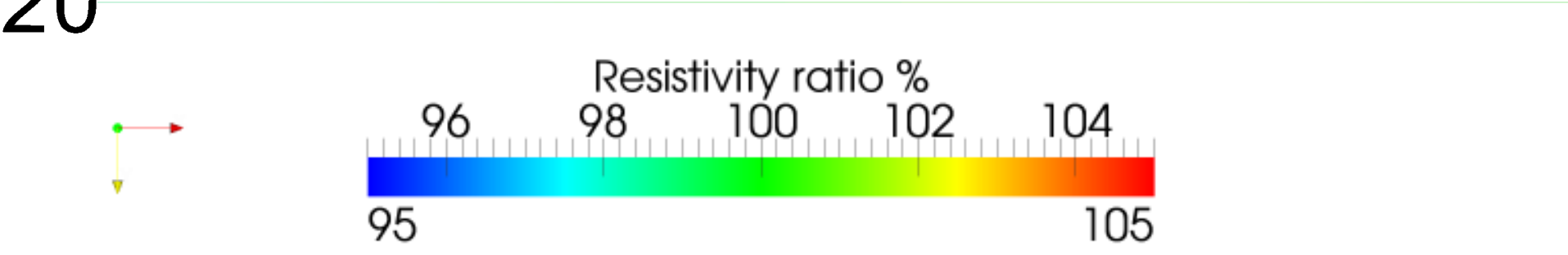
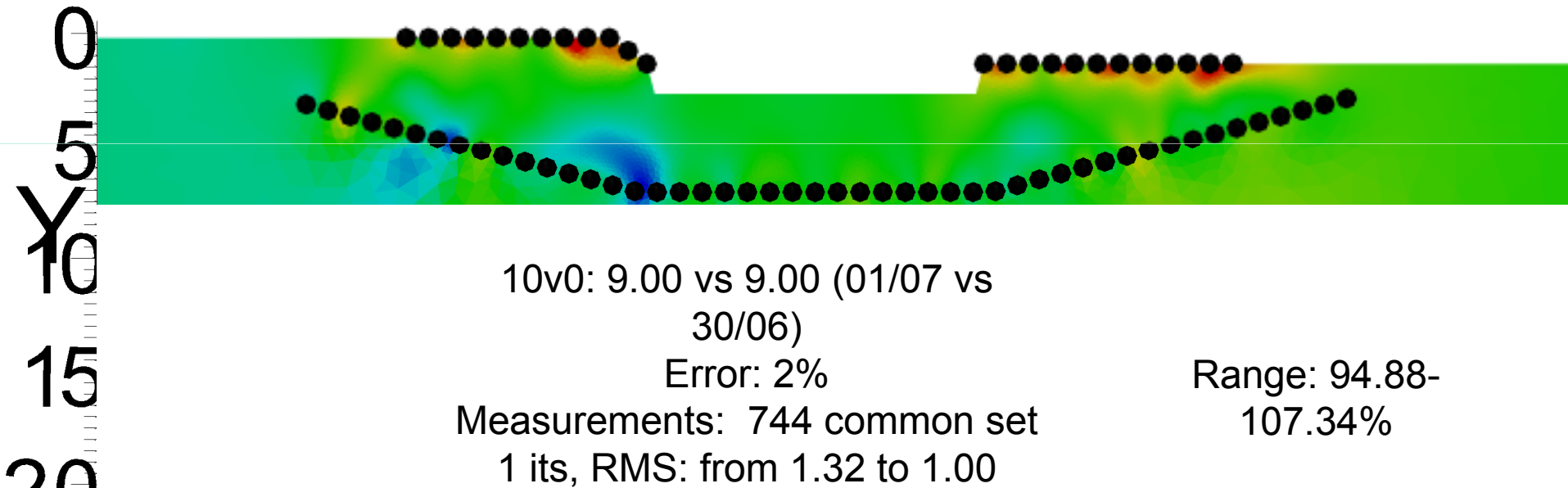
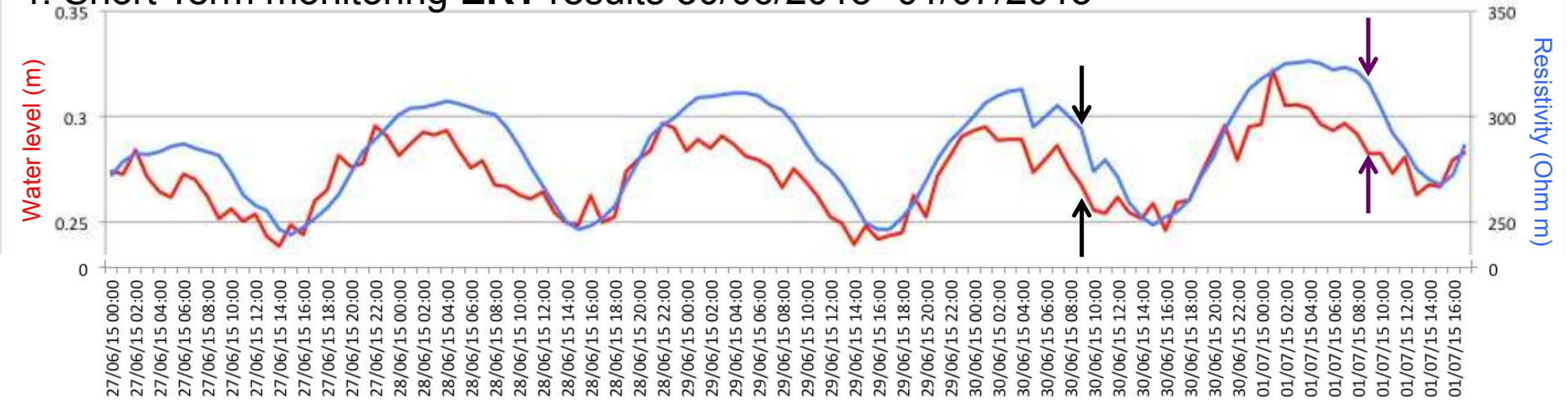


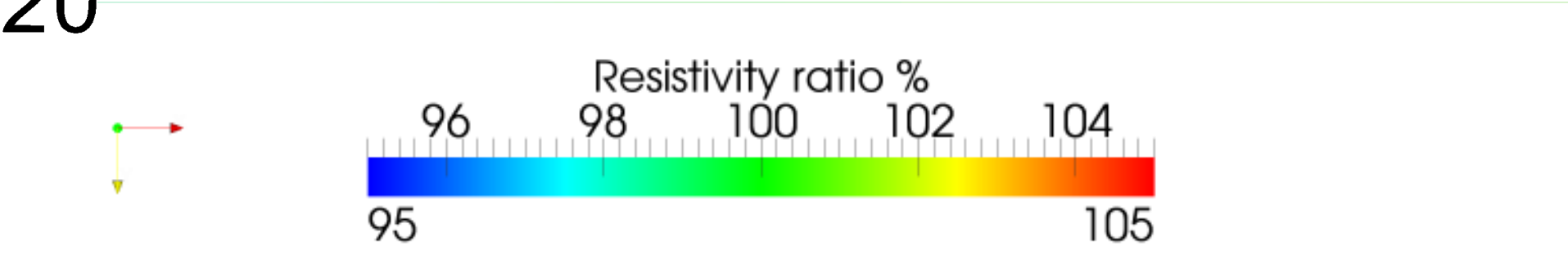
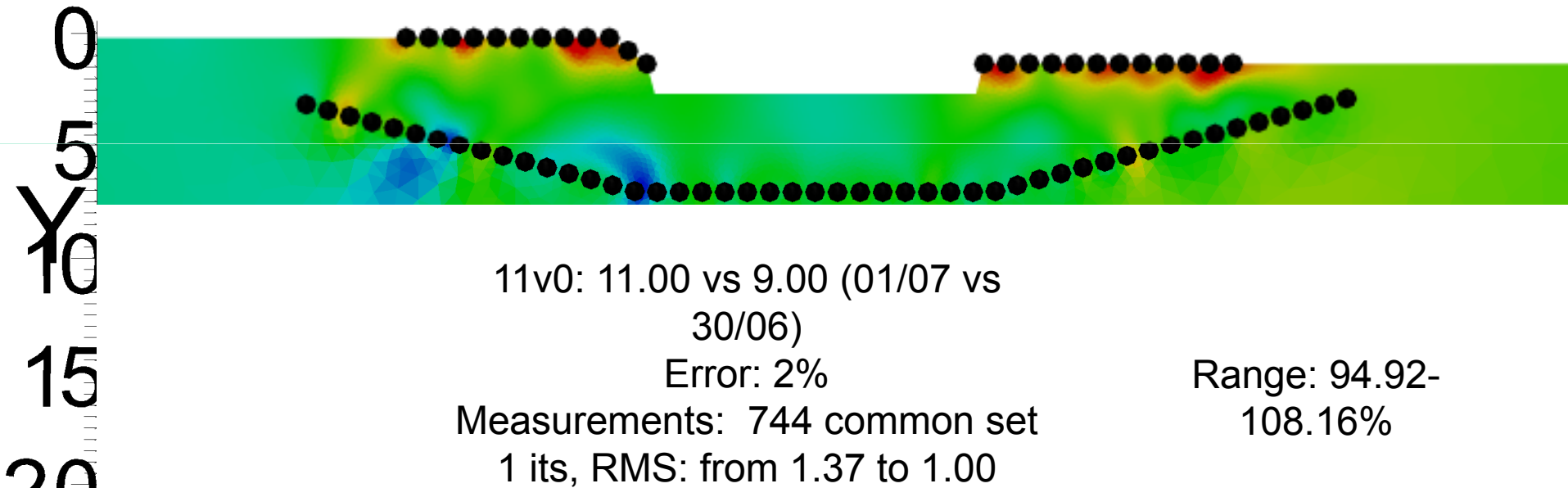
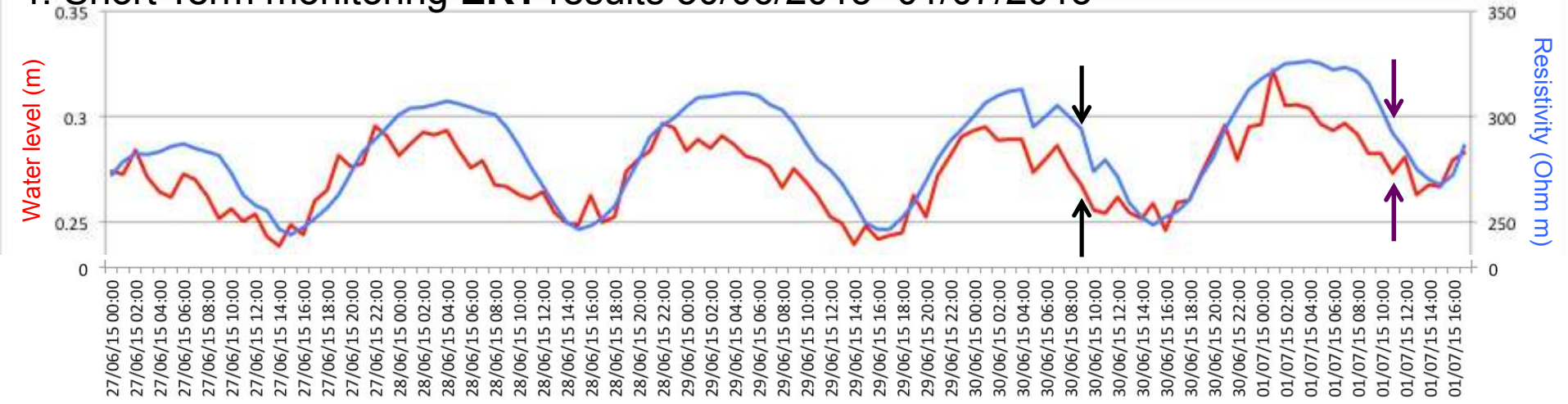


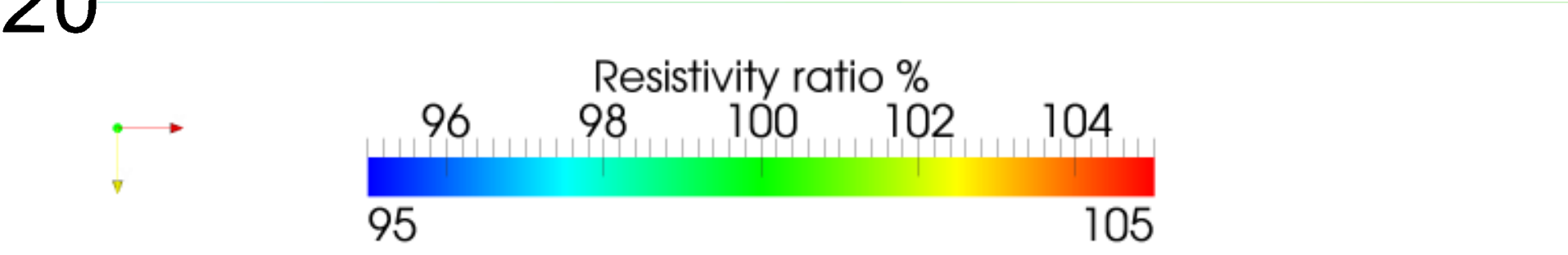
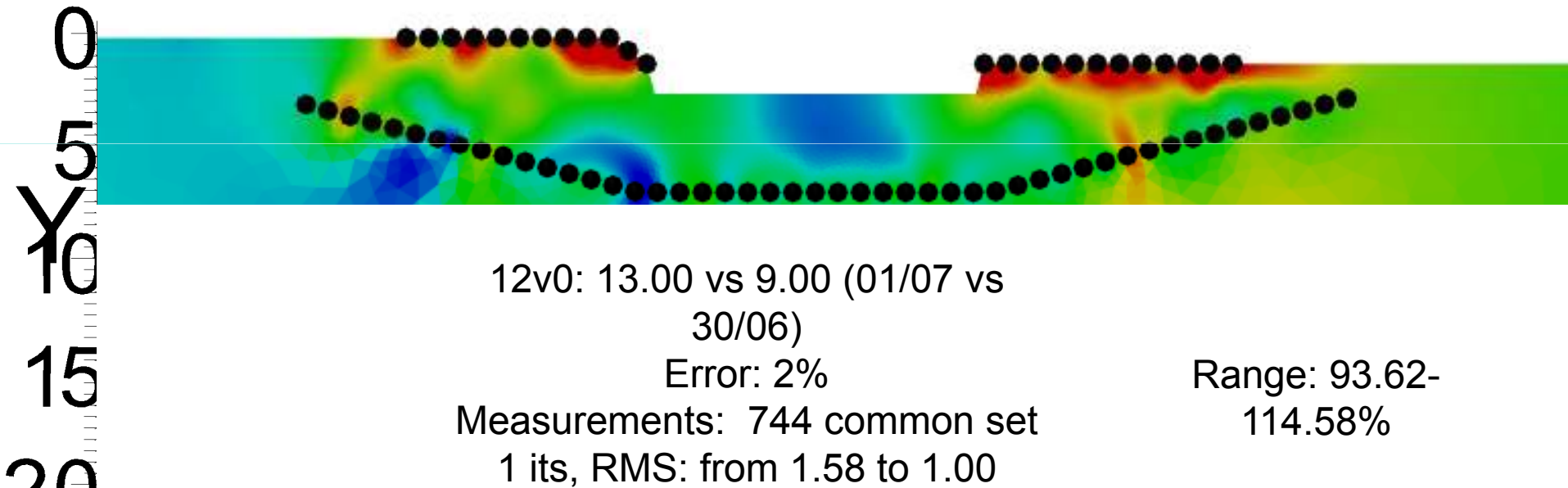
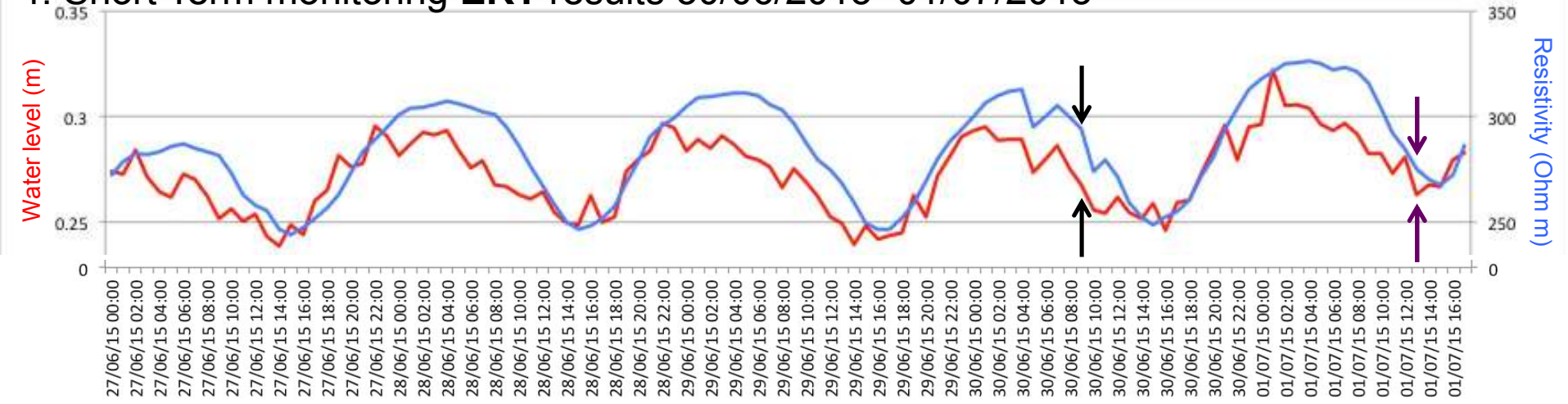


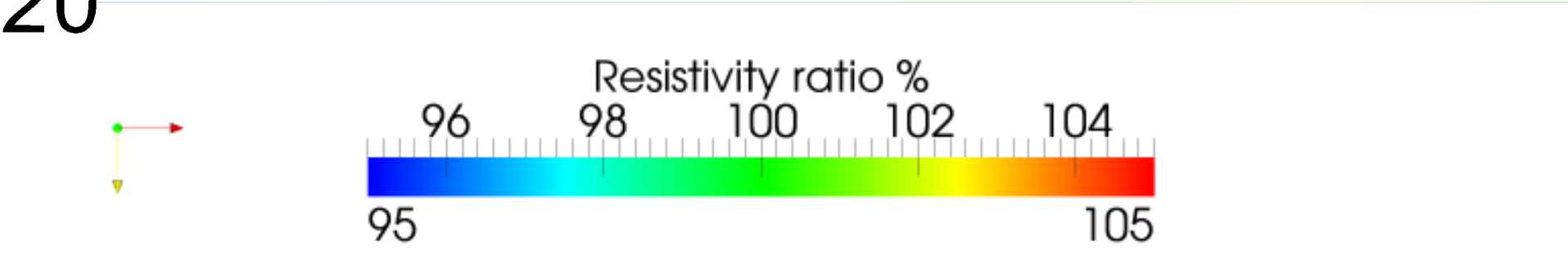
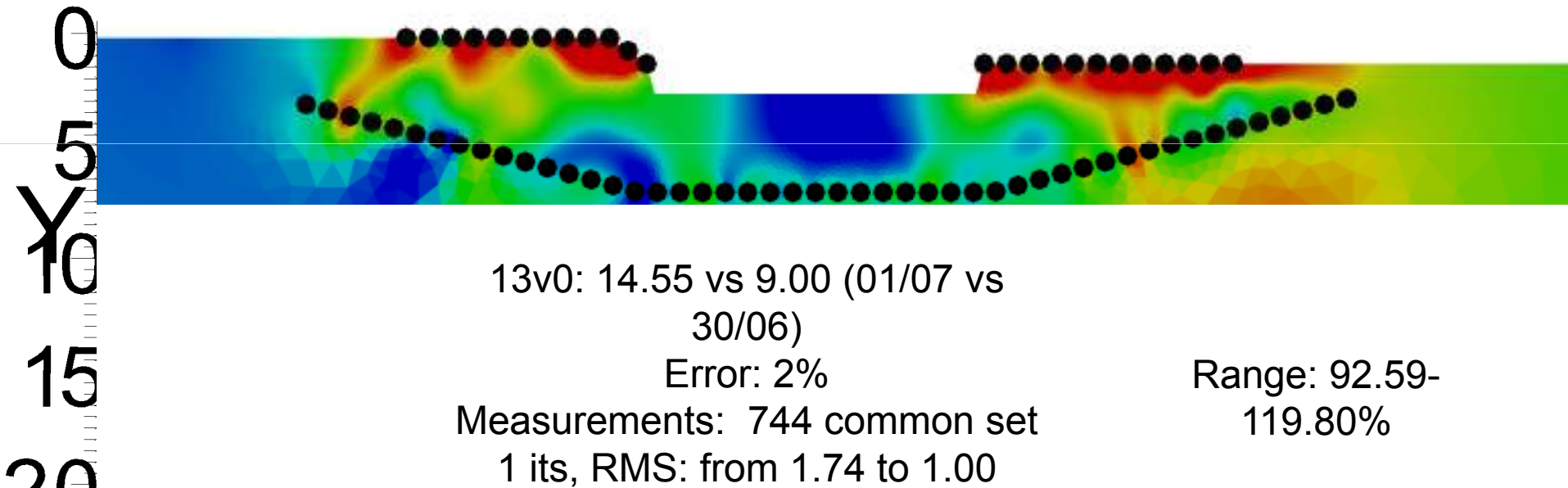
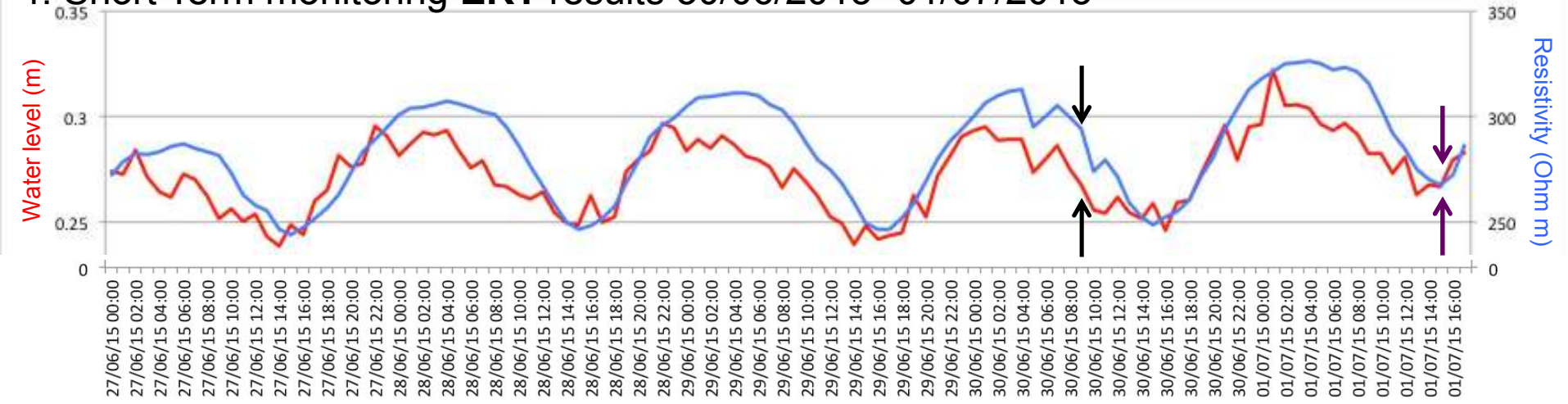


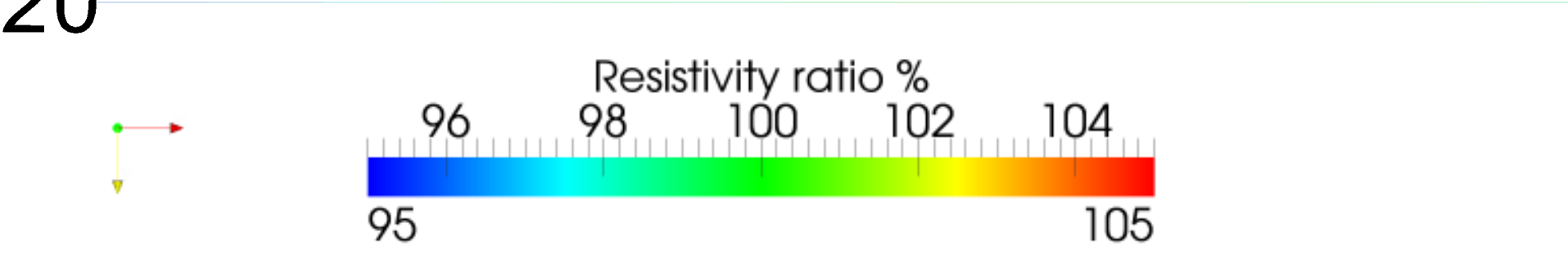
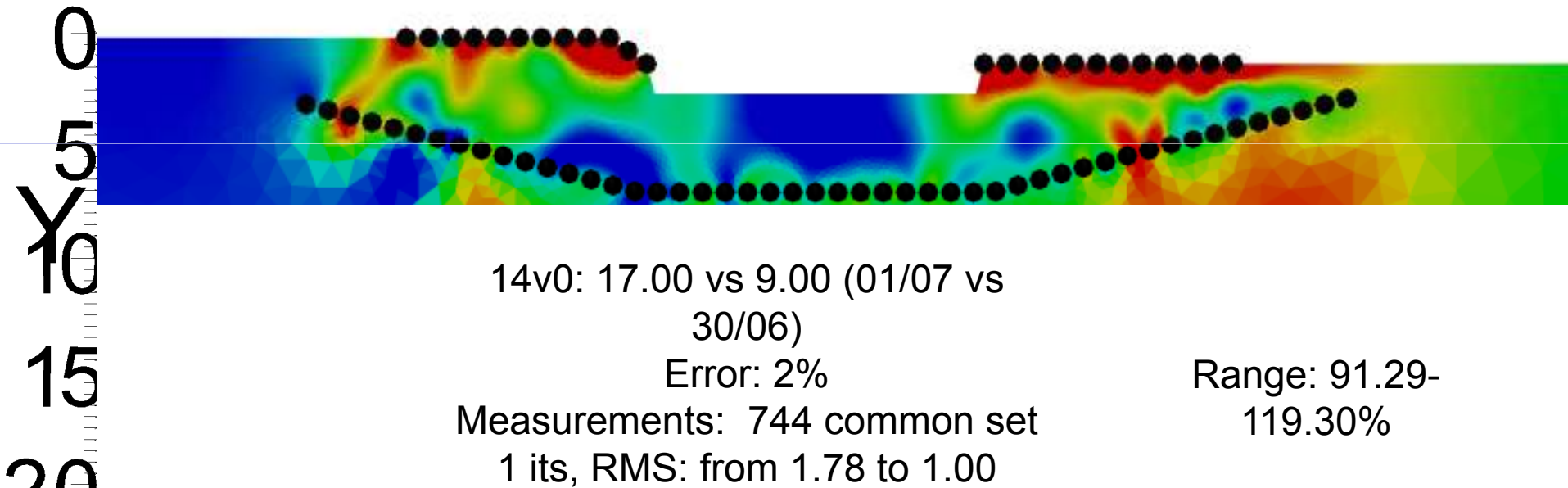
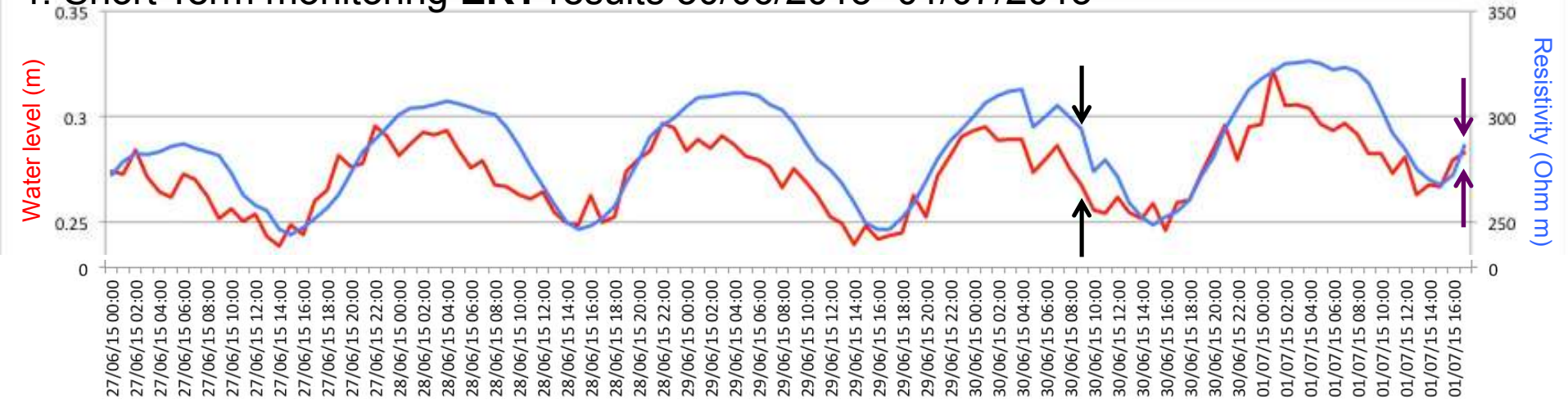


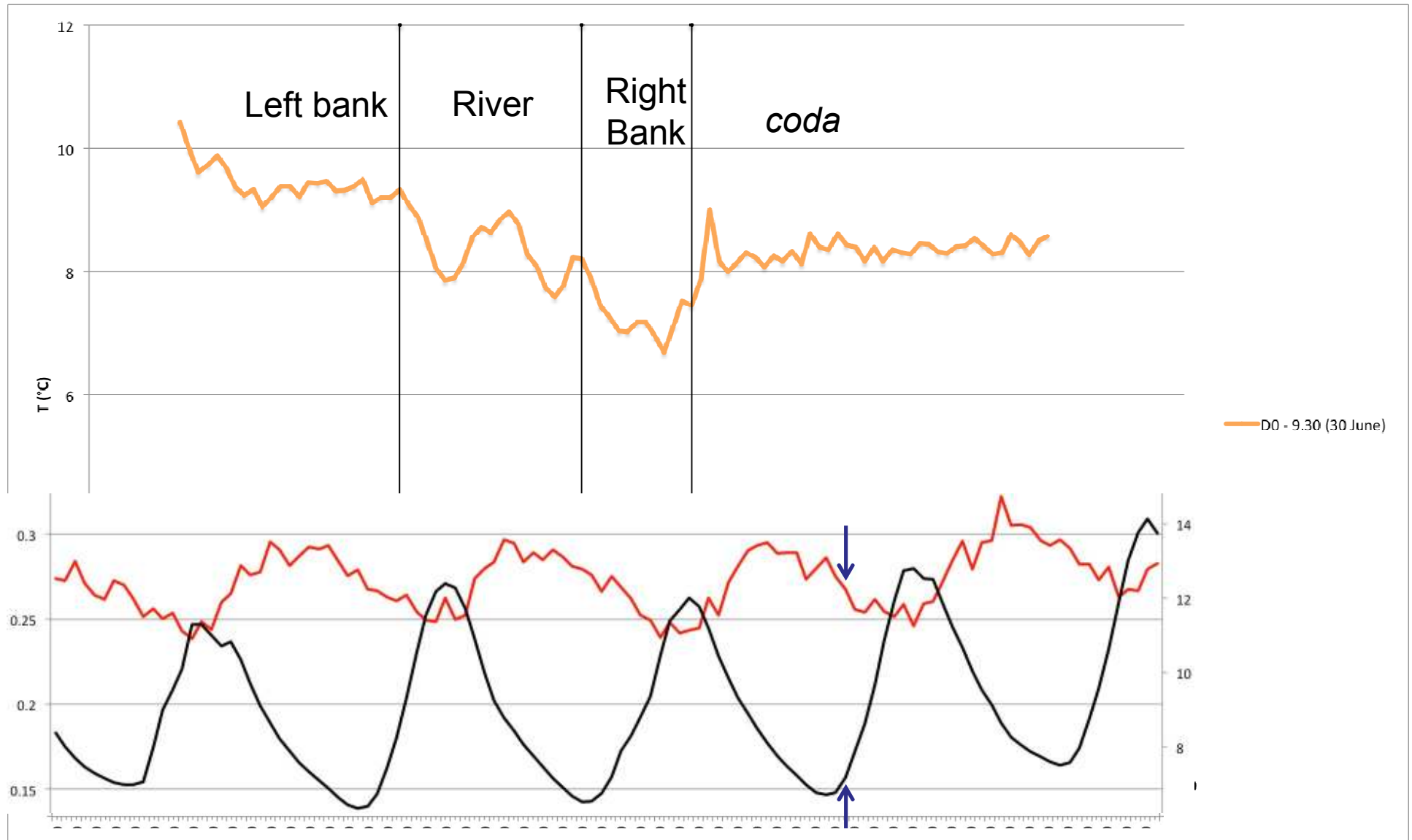




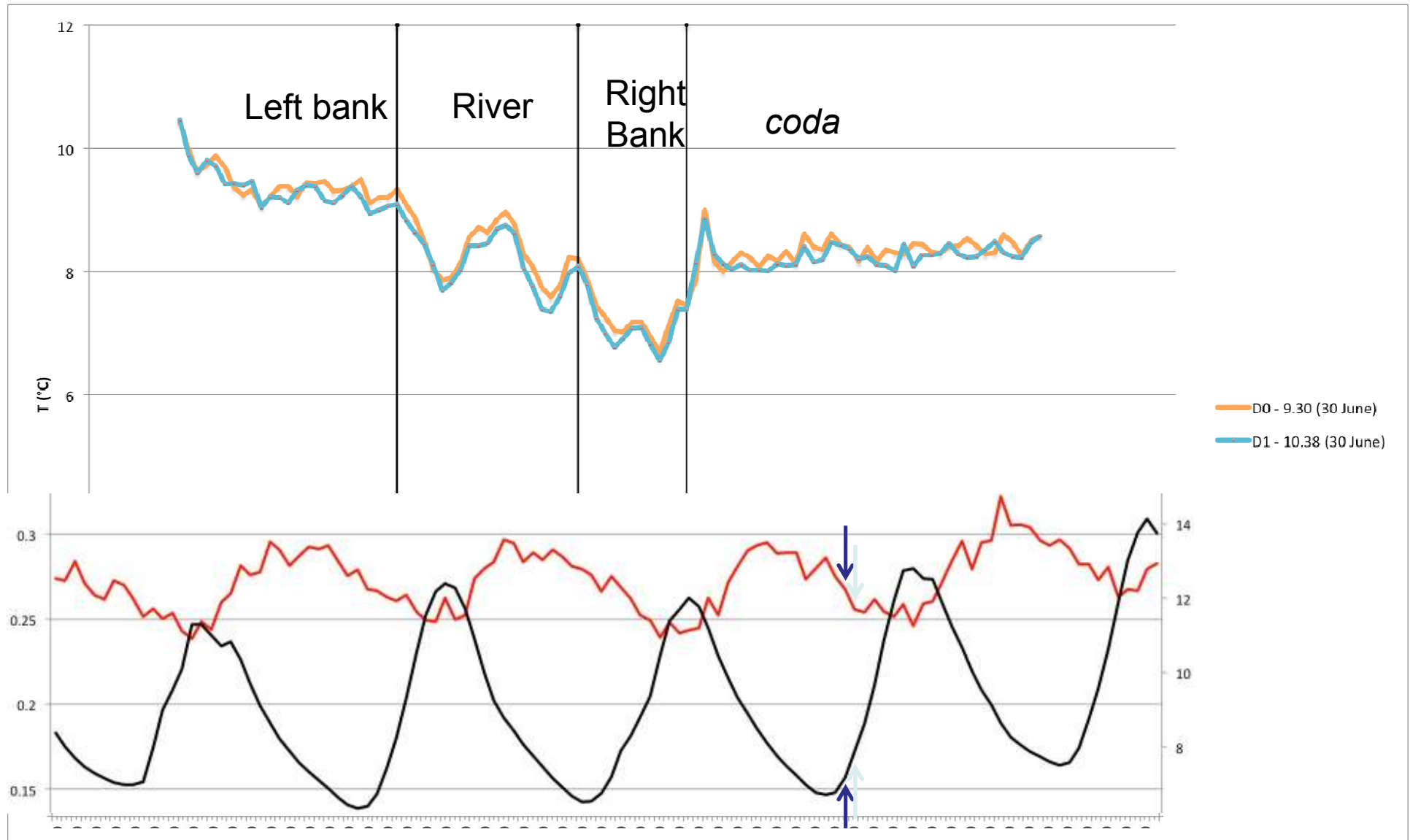




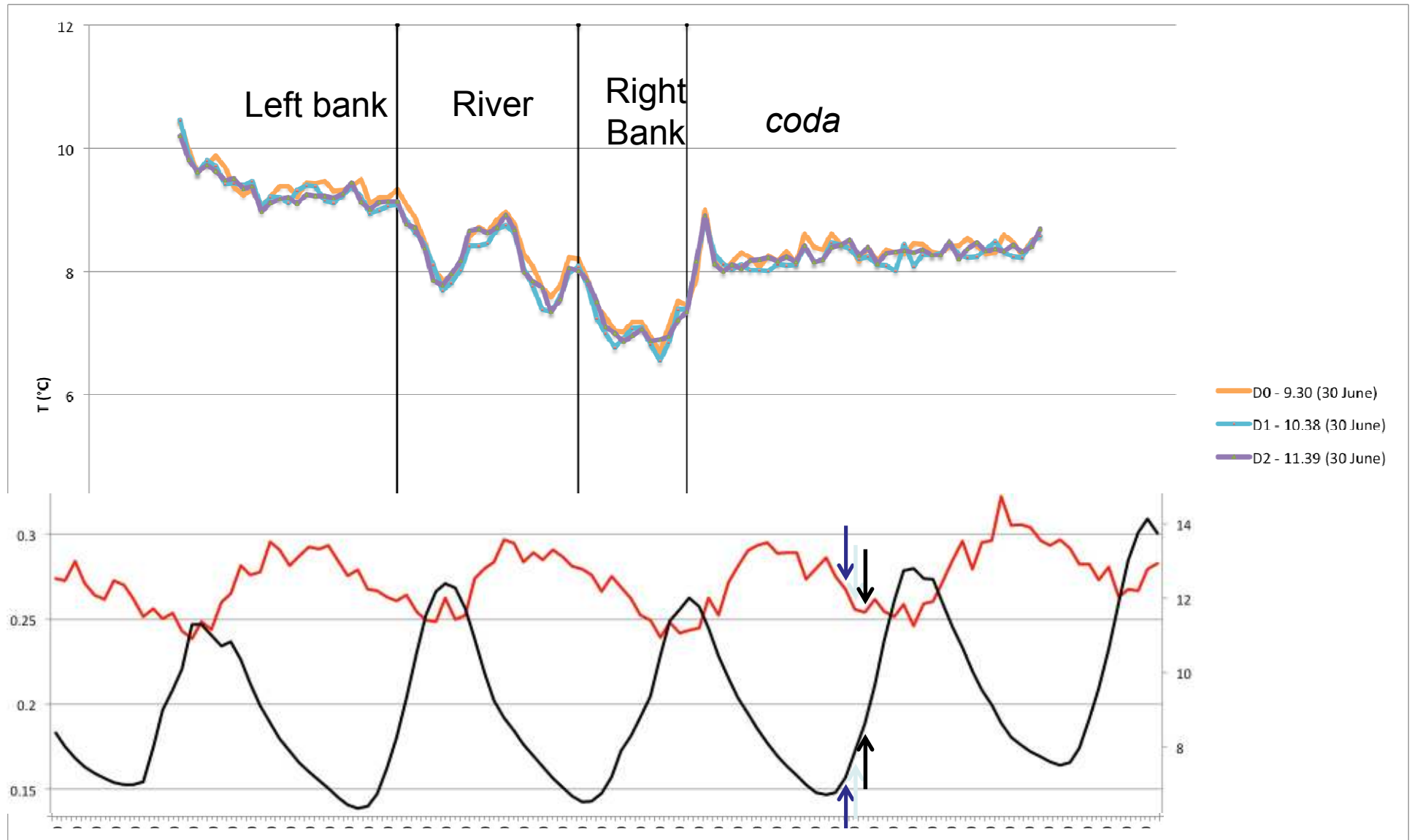




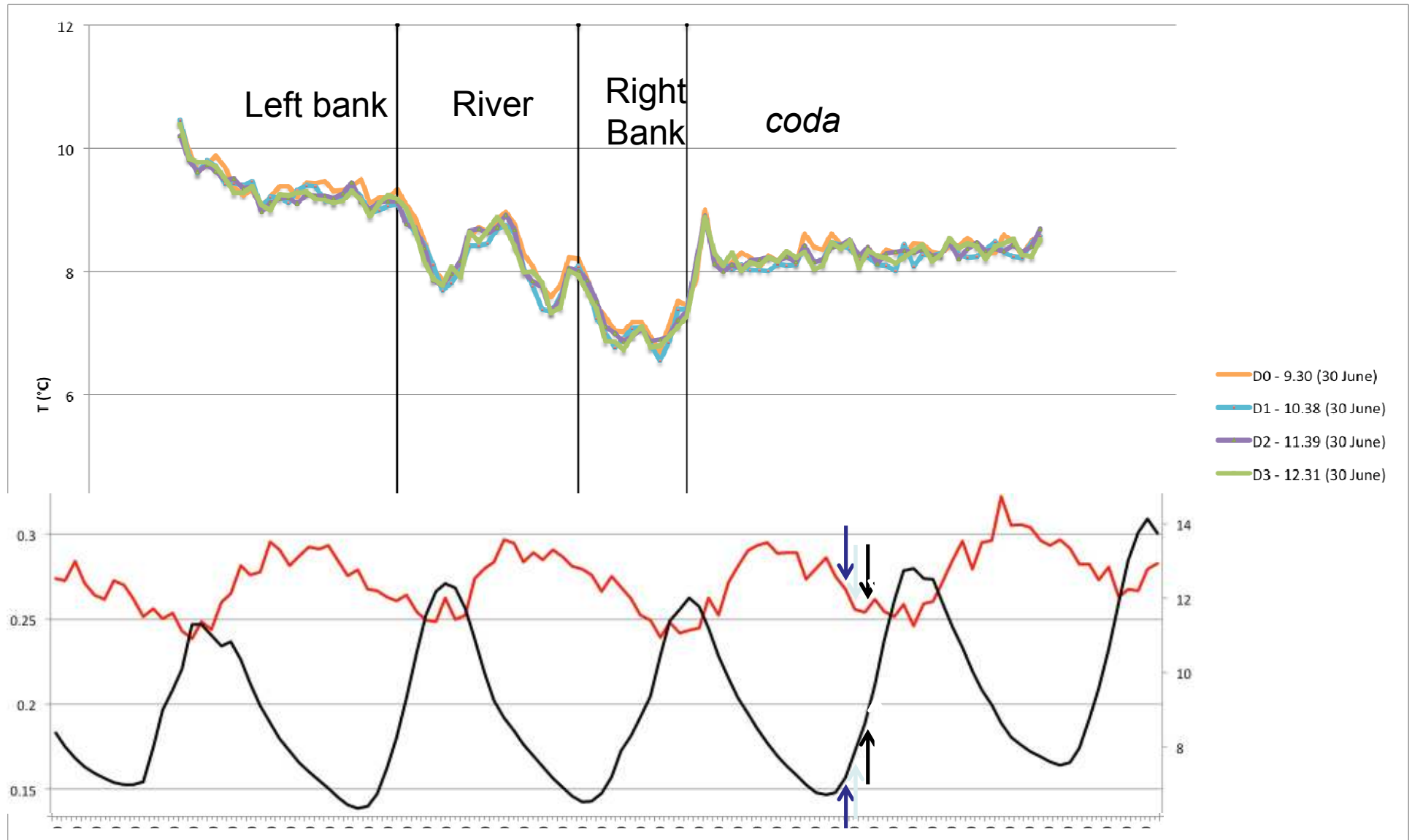
River water level and temperature (27 June – 01 July)



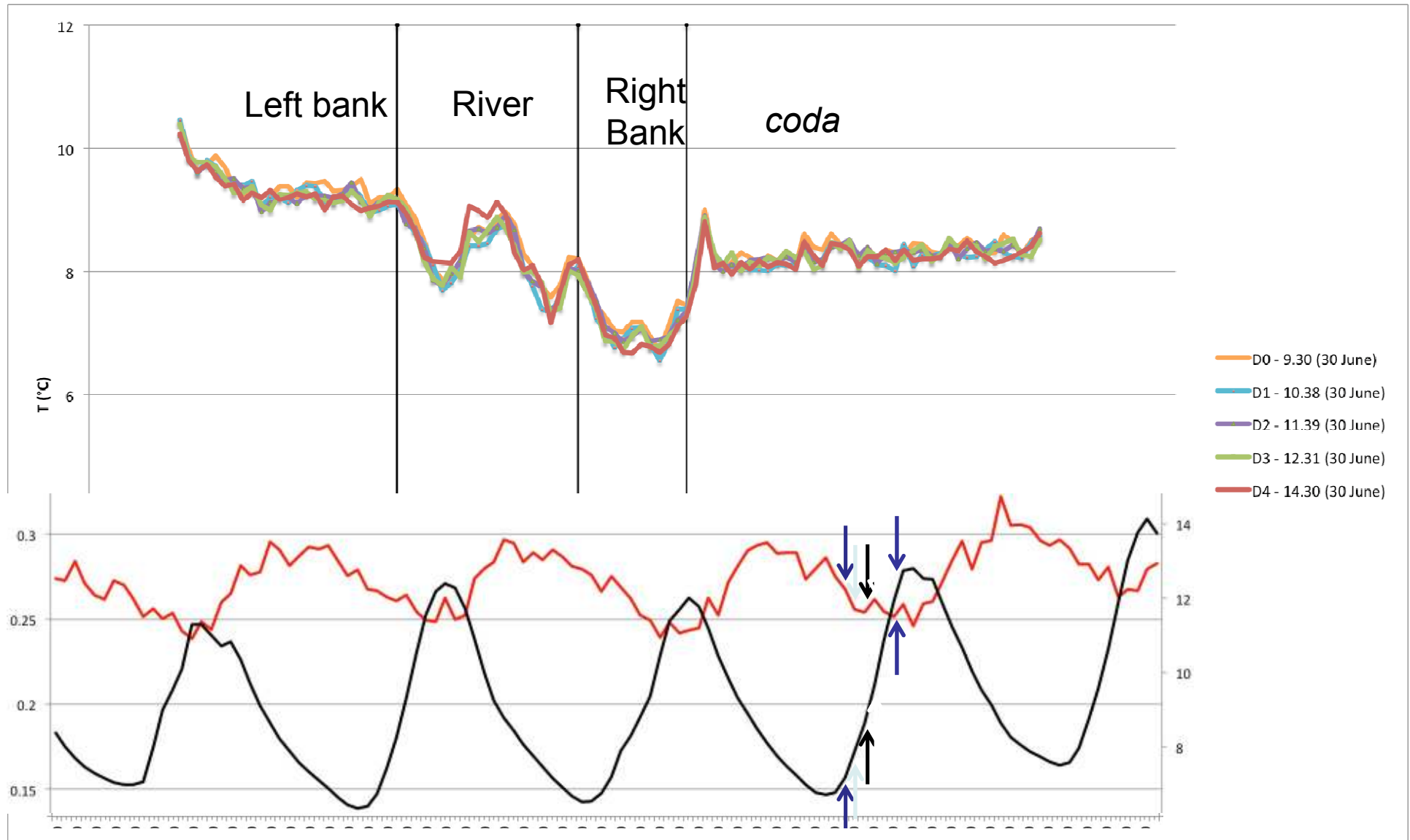
River water level and temperature (27 June – 01 July)



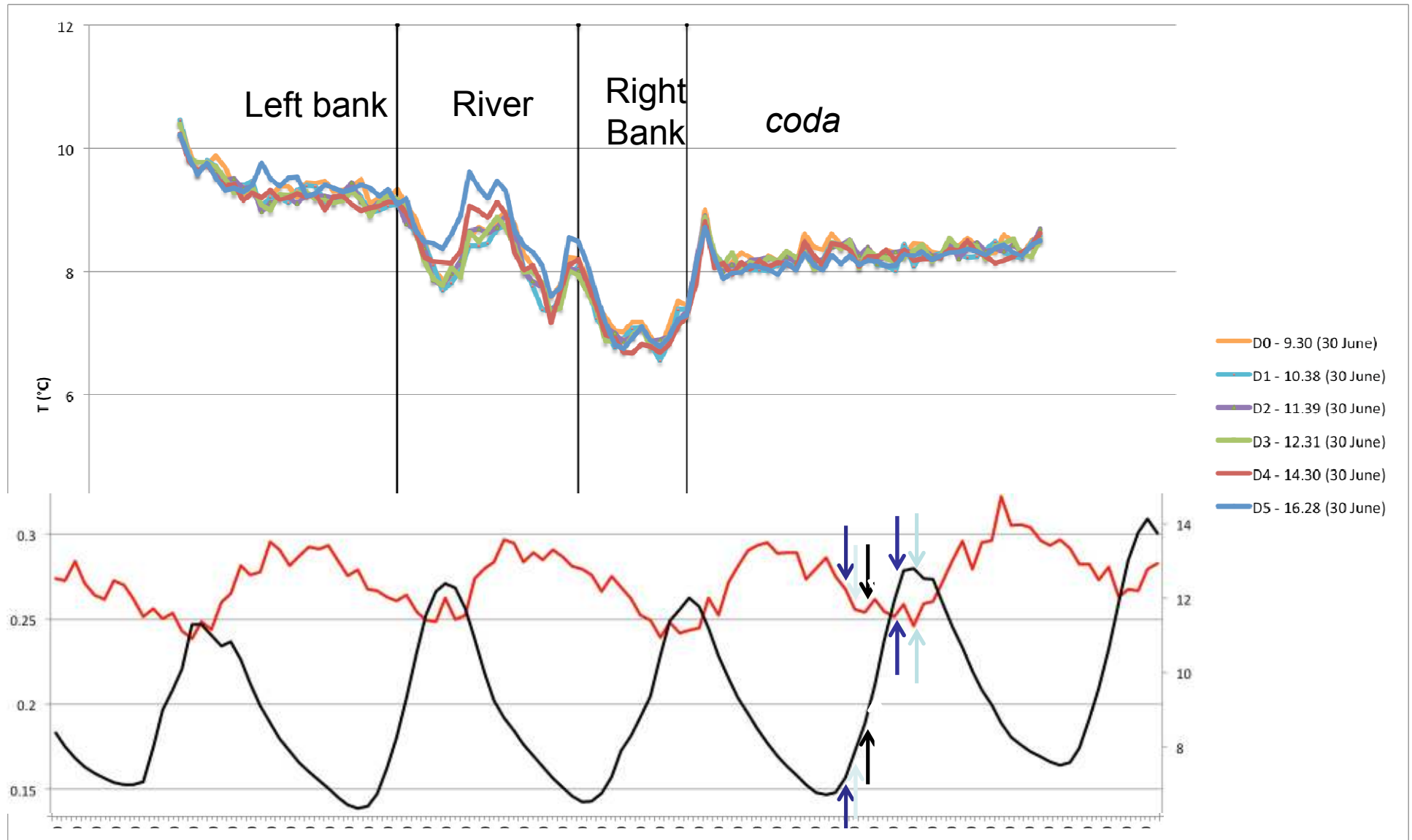
River water level and temperature (27 June – 01 July)



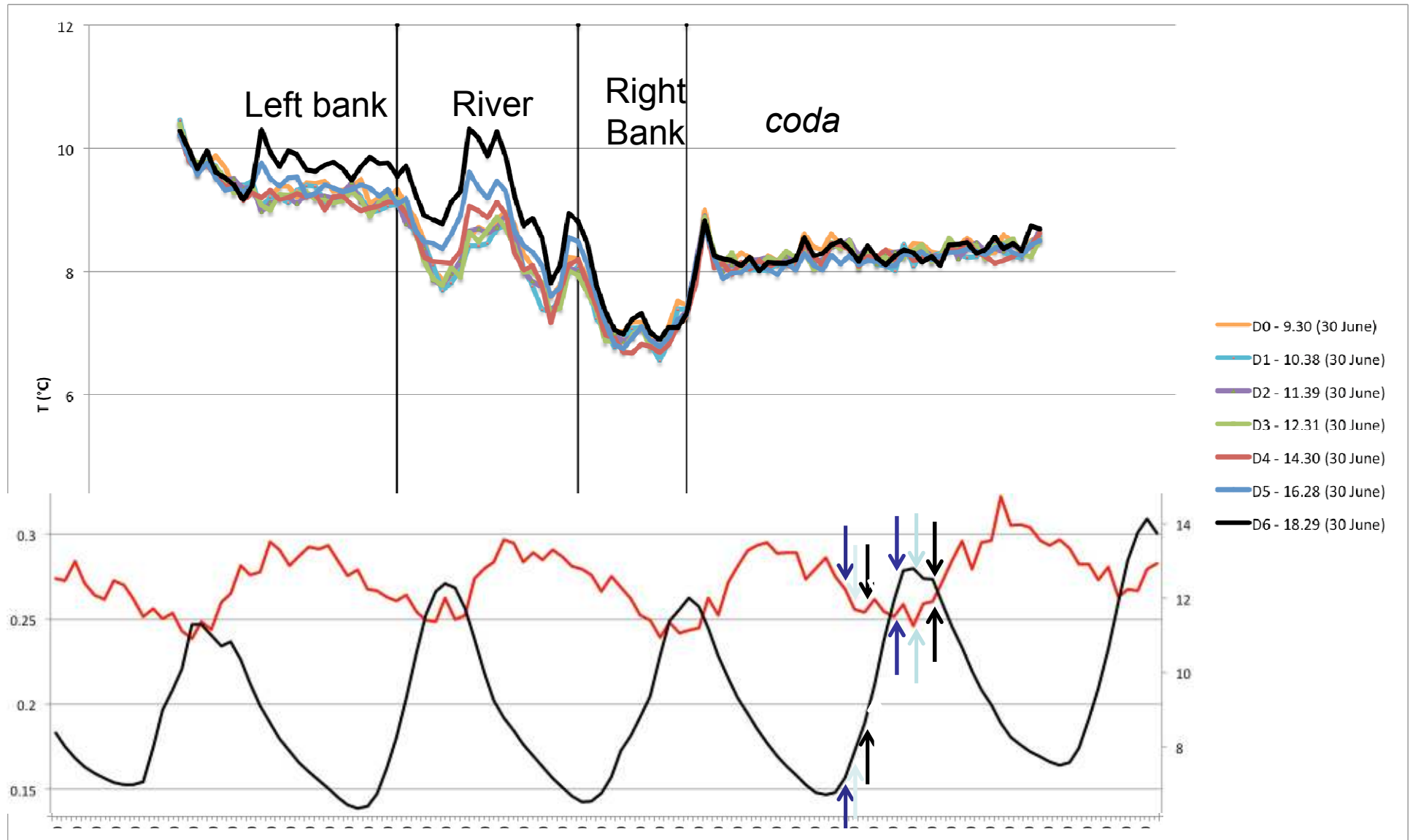
River water level and temperature (27 June – 01 July)



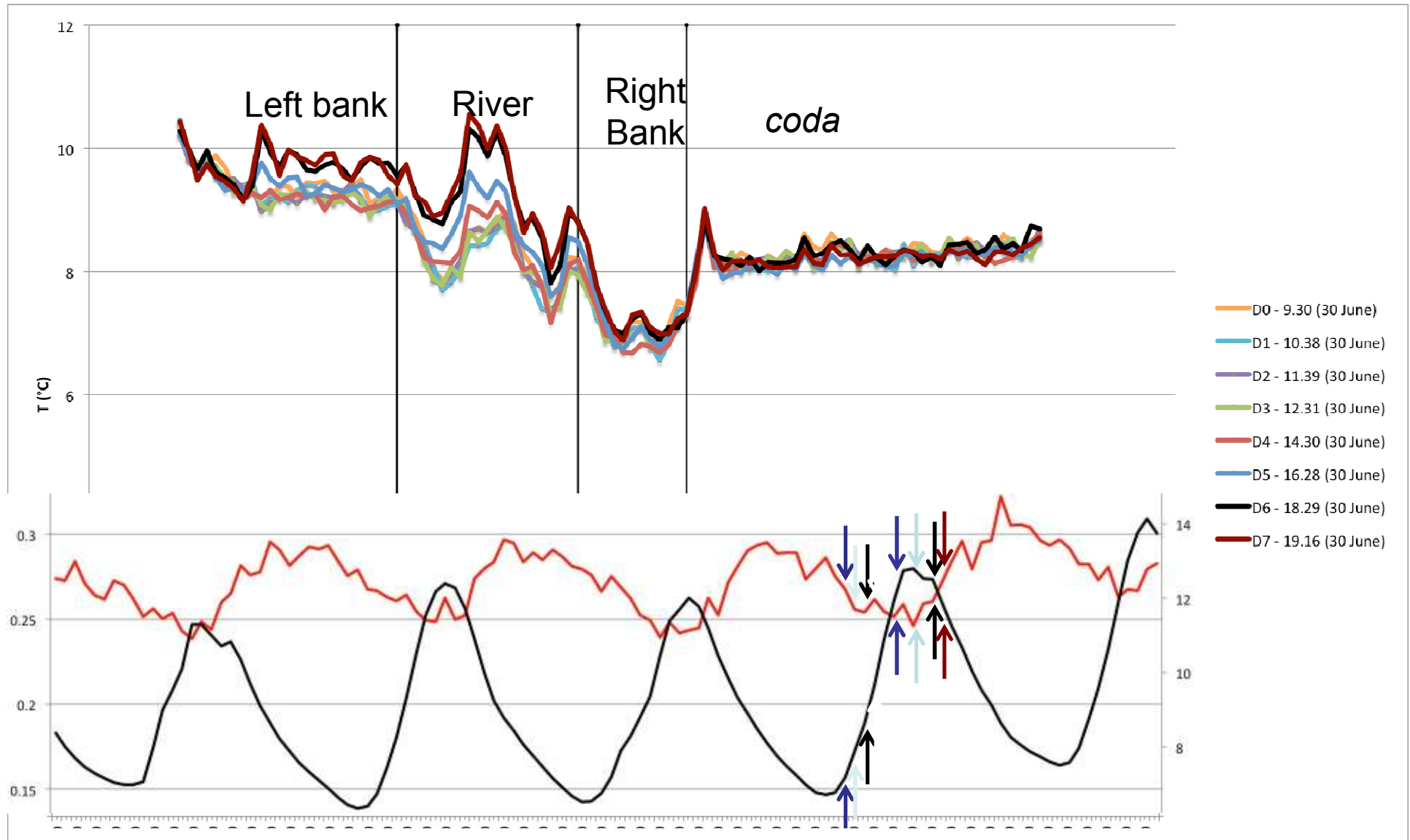
River water level and temperature (27 June – 01 July)



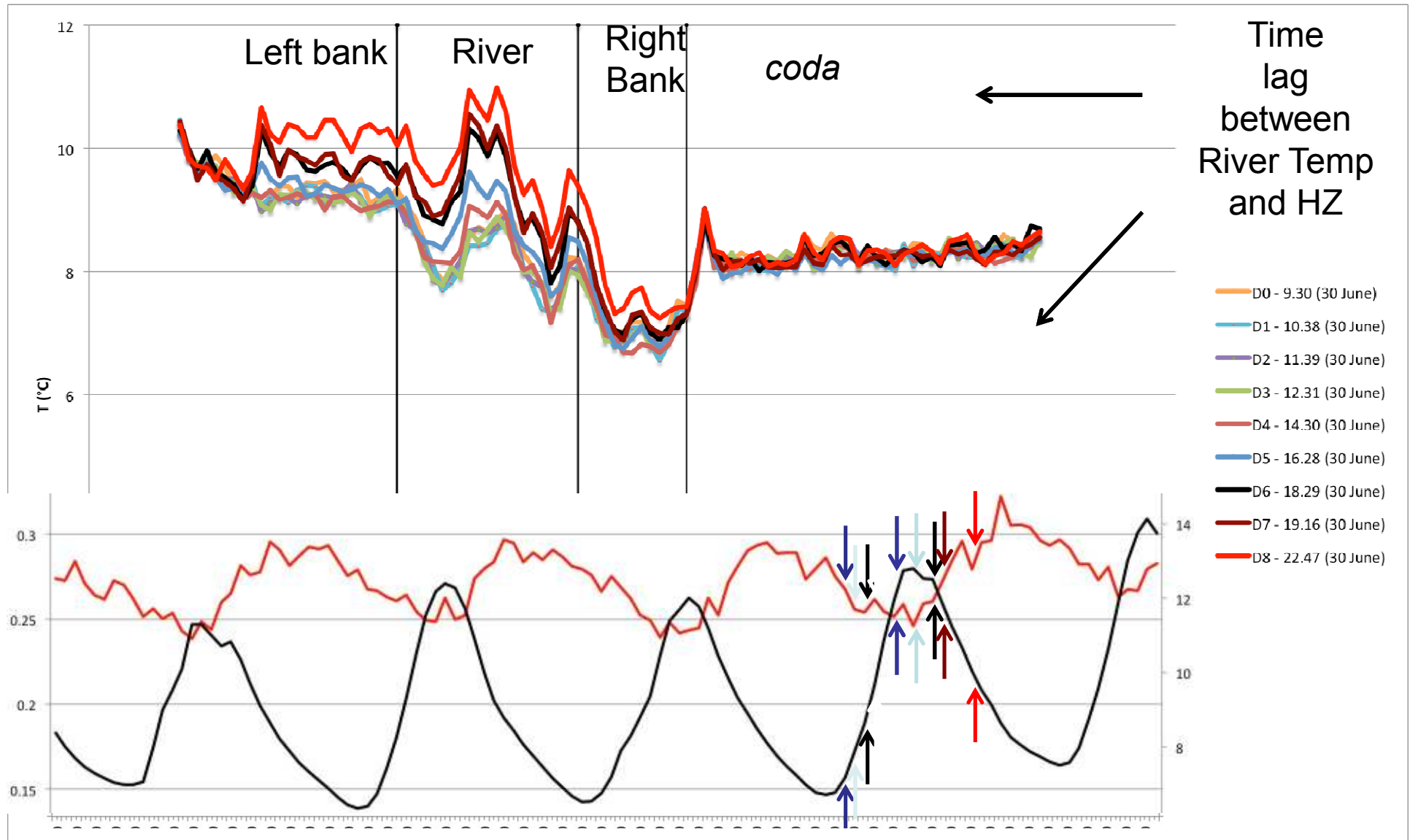
River water level and temperature (27 June – 01 July)



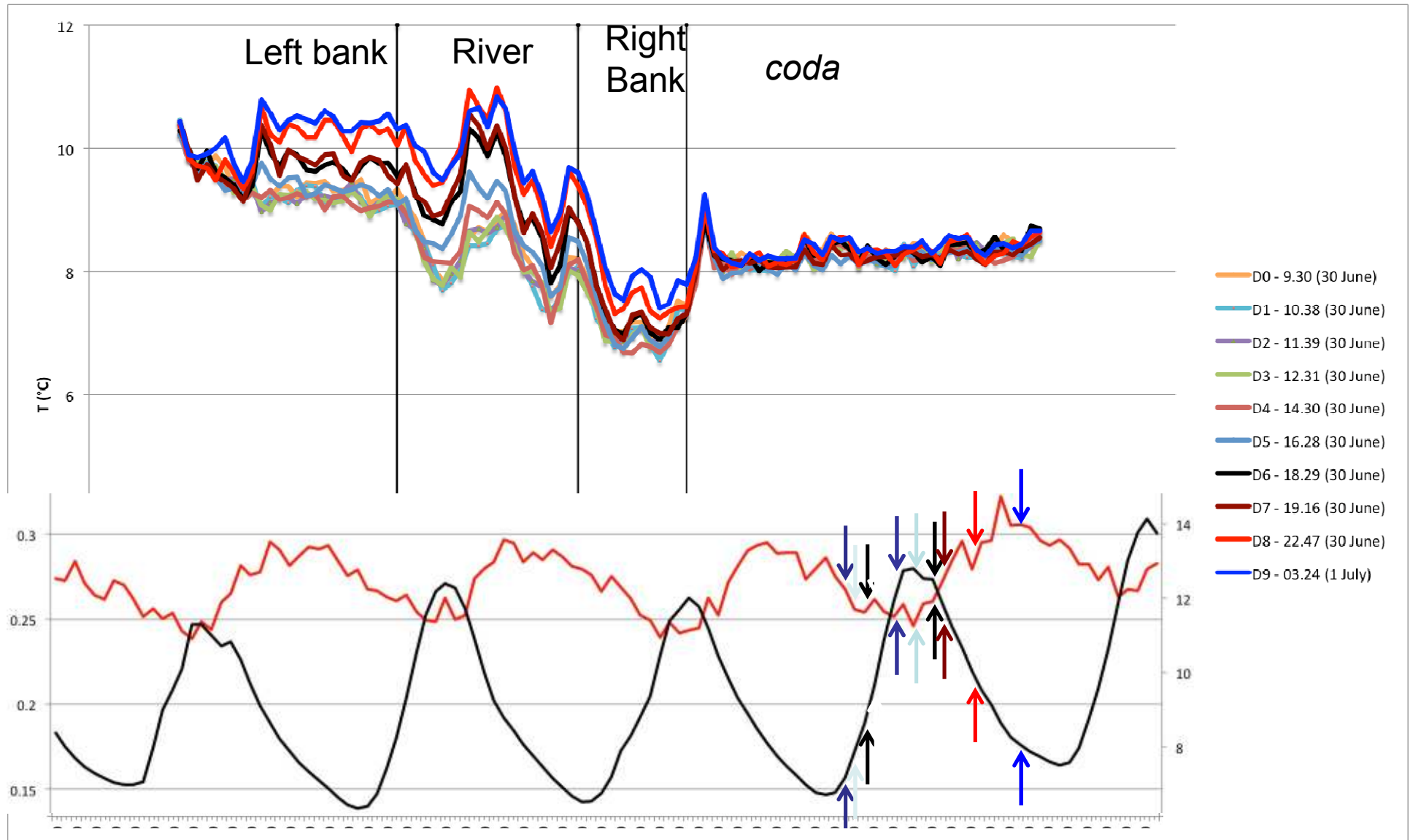
River water level and temperature (27 June – 01 July)



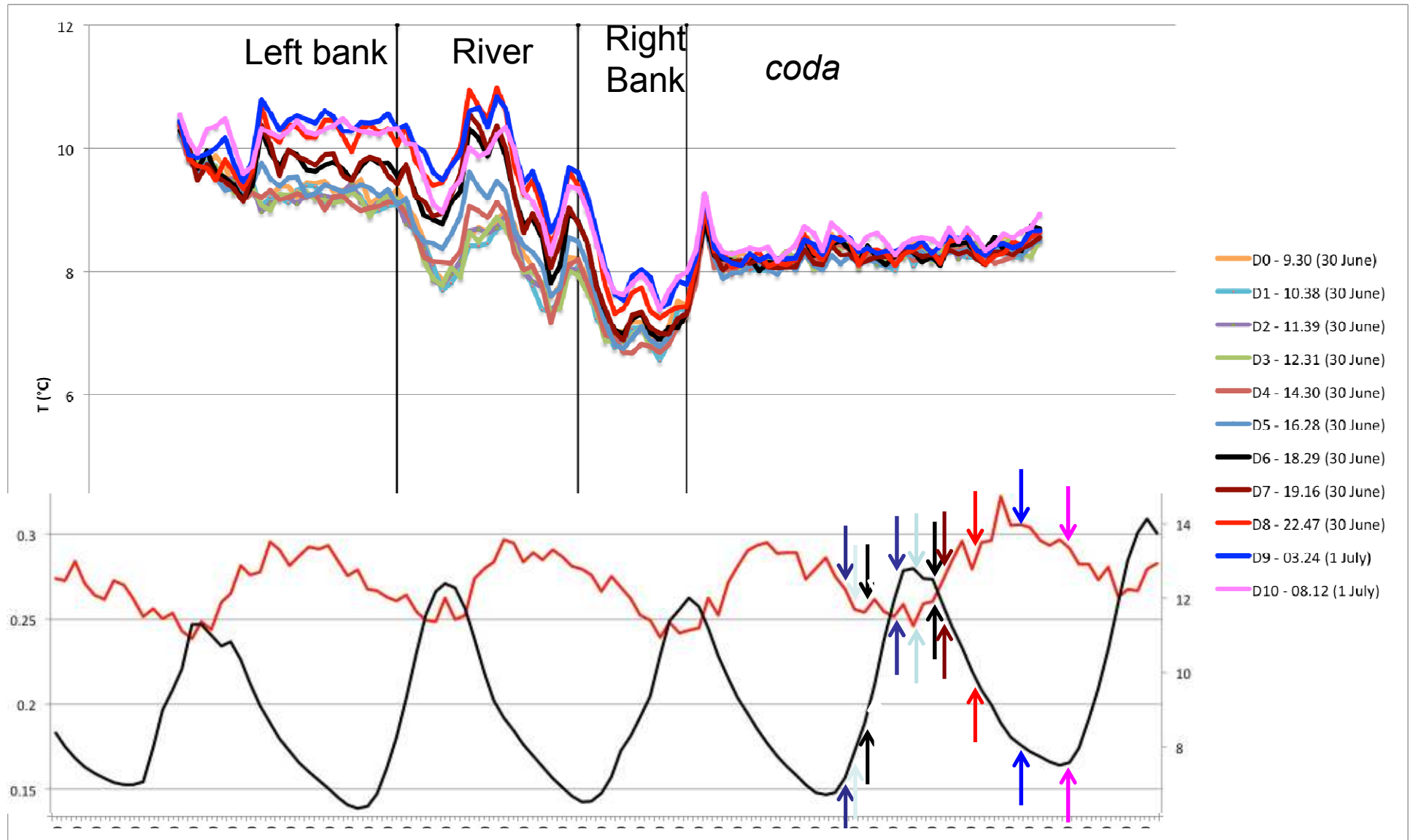
River water level and temperature (27 June – 01 July)



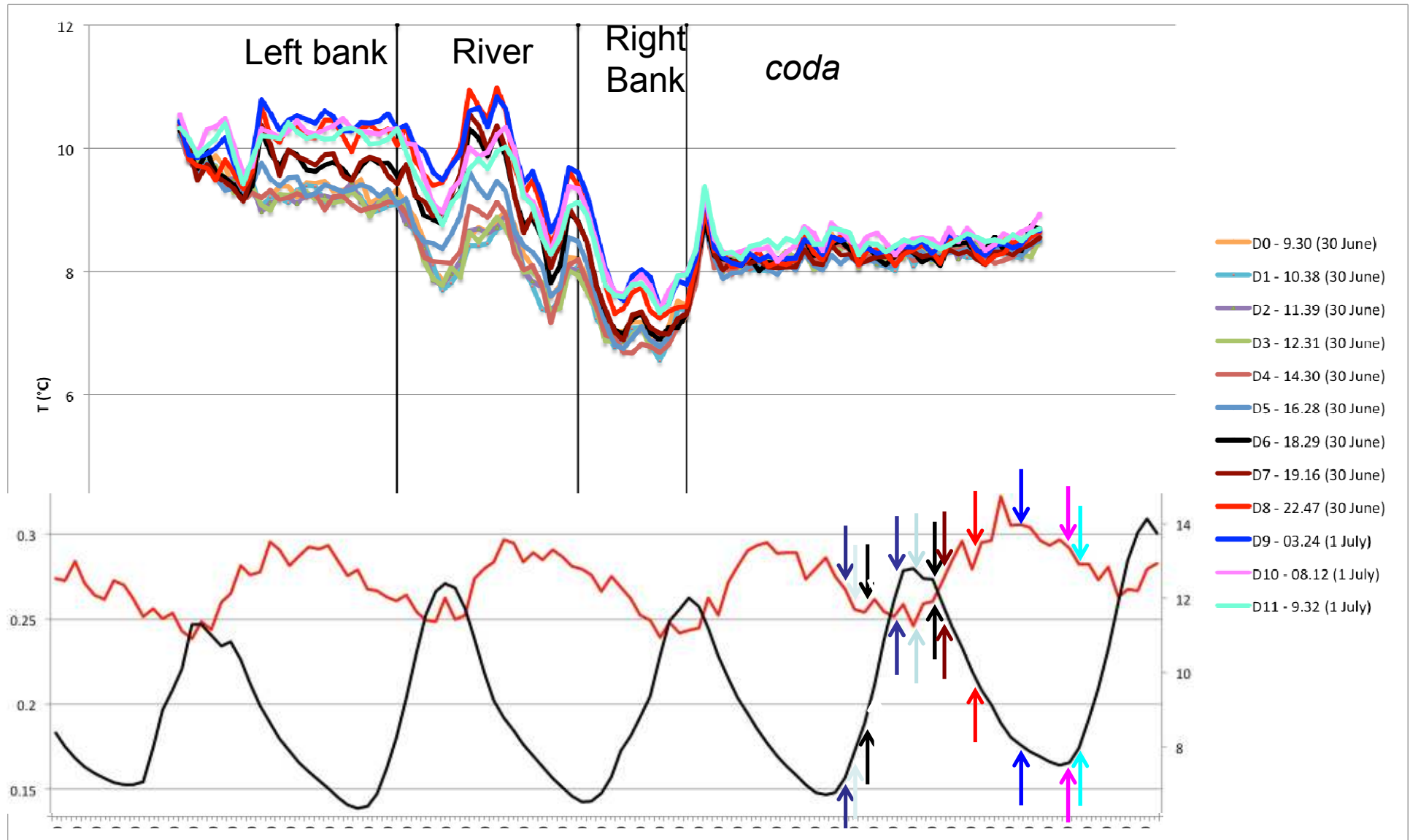
River water level and temperature (27 June – 01 July)



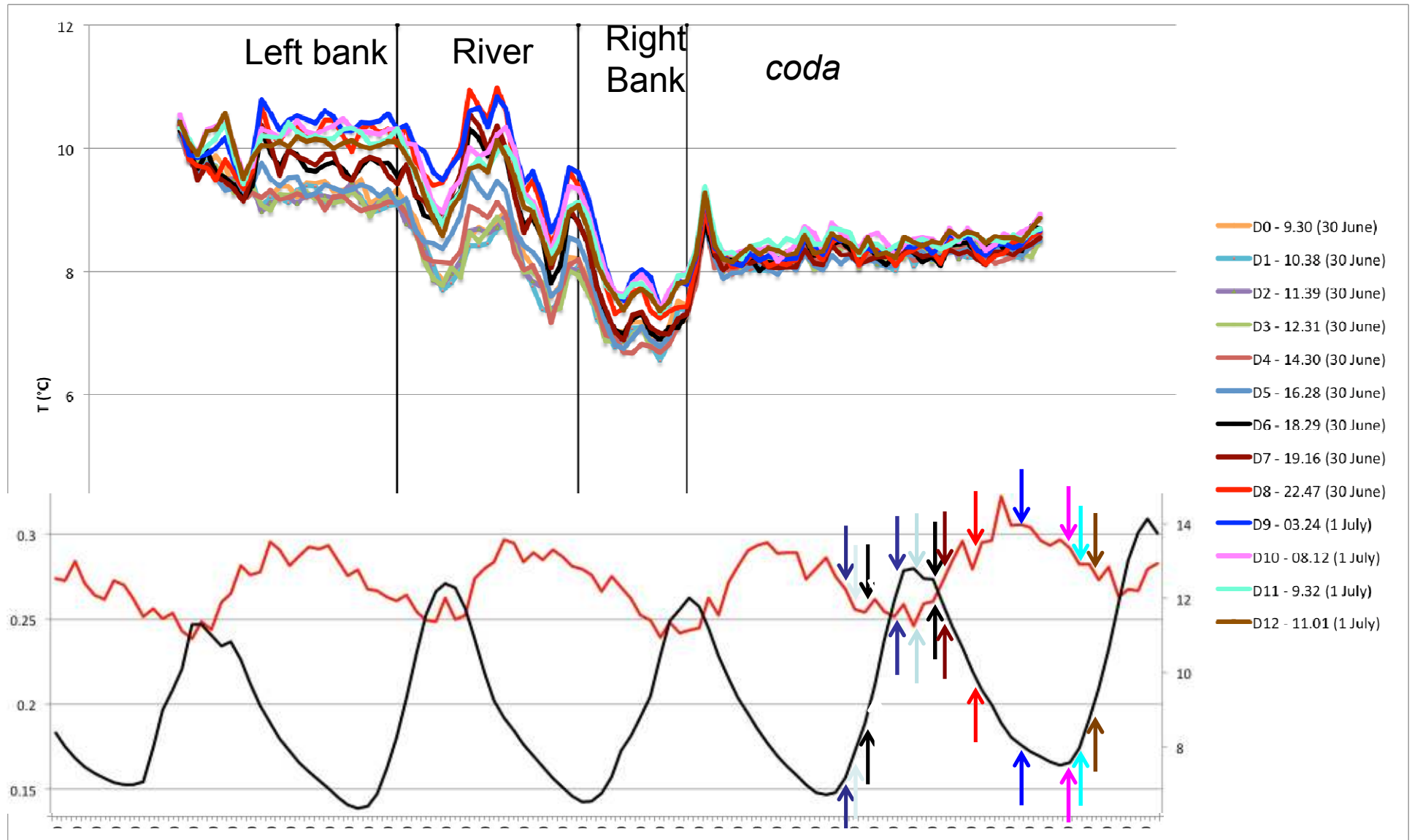
River water level and temperature (27 June – 01 July)



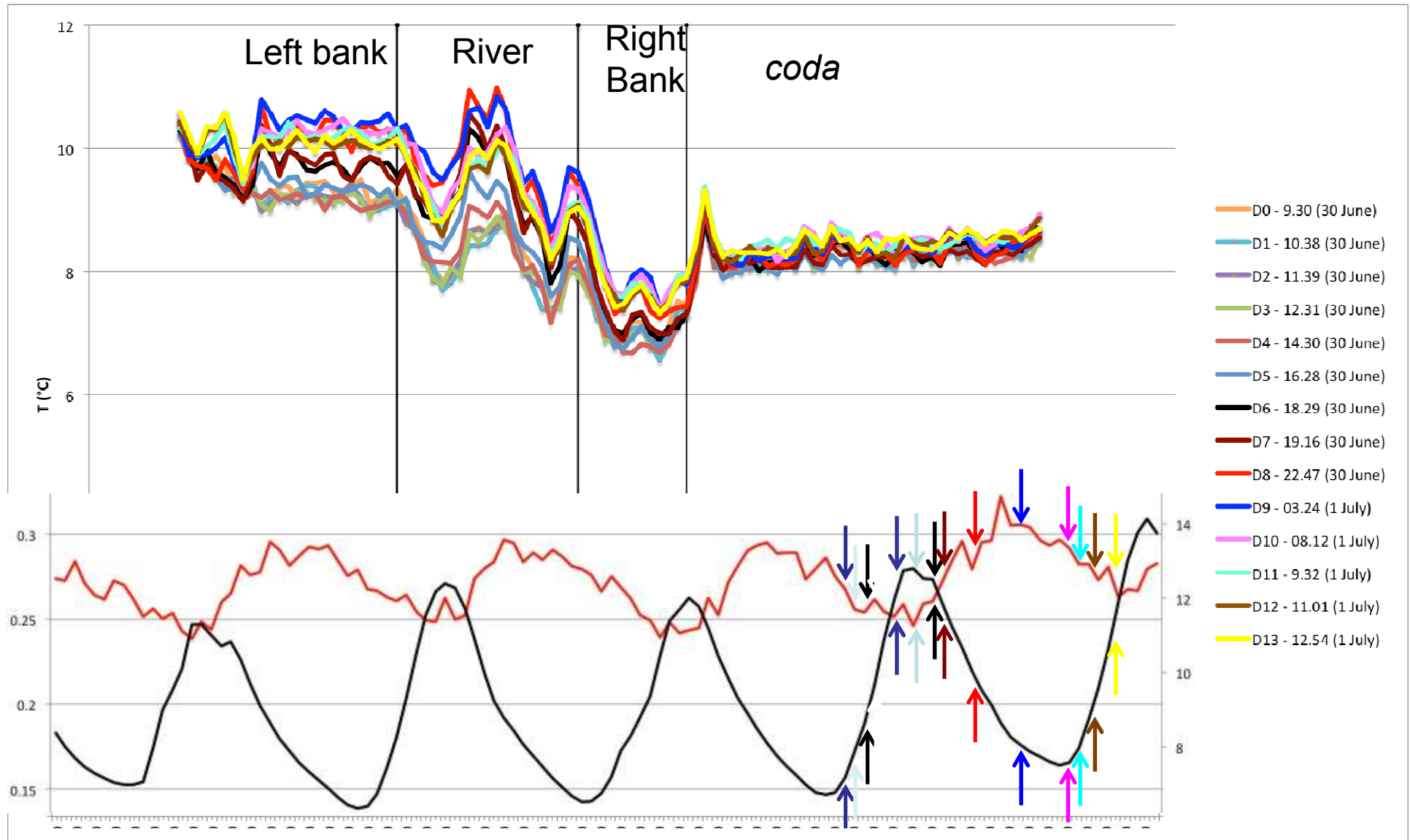
River water level and temperature (27 June – 01 July)



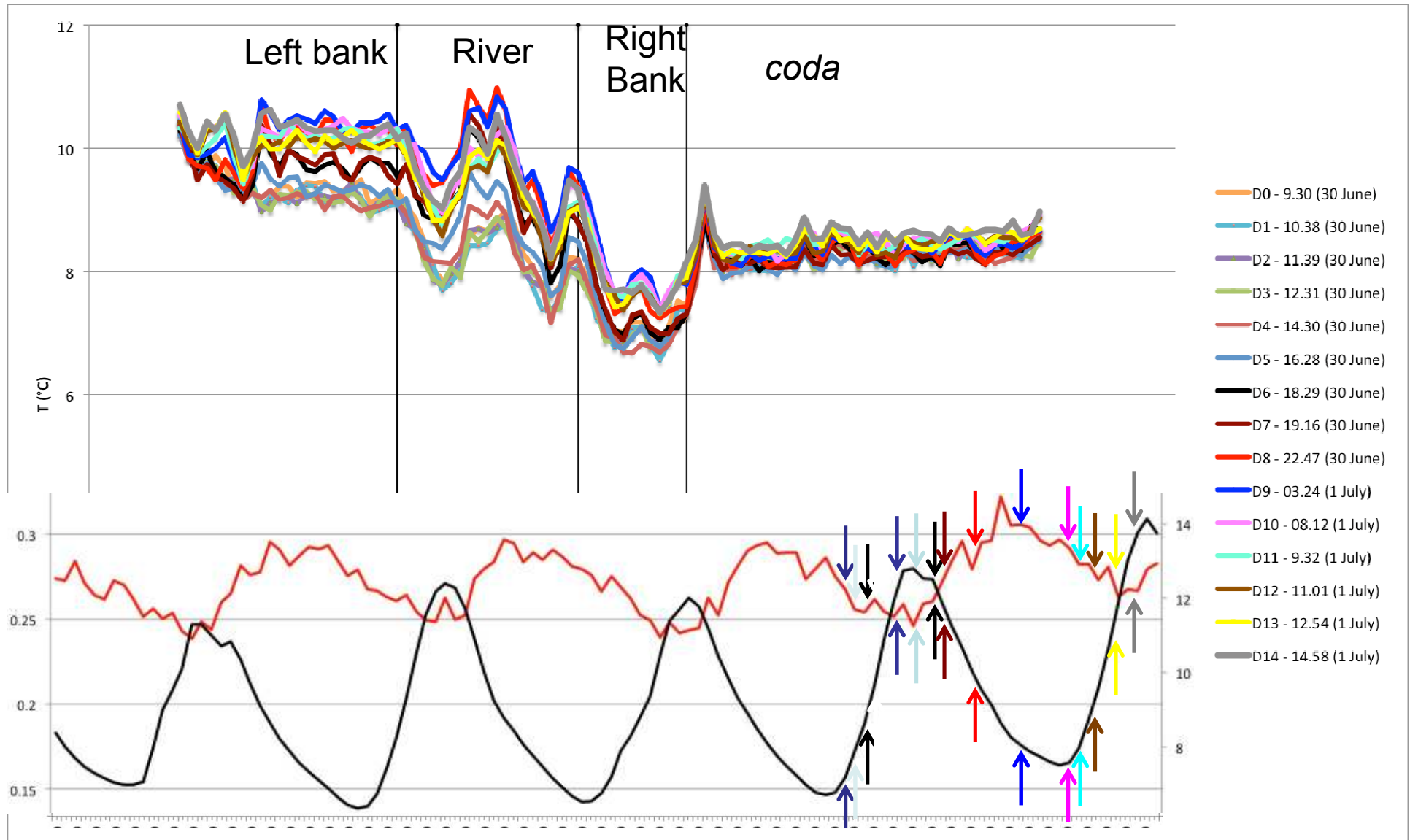
River water level and temperature (27 June – 01 July)



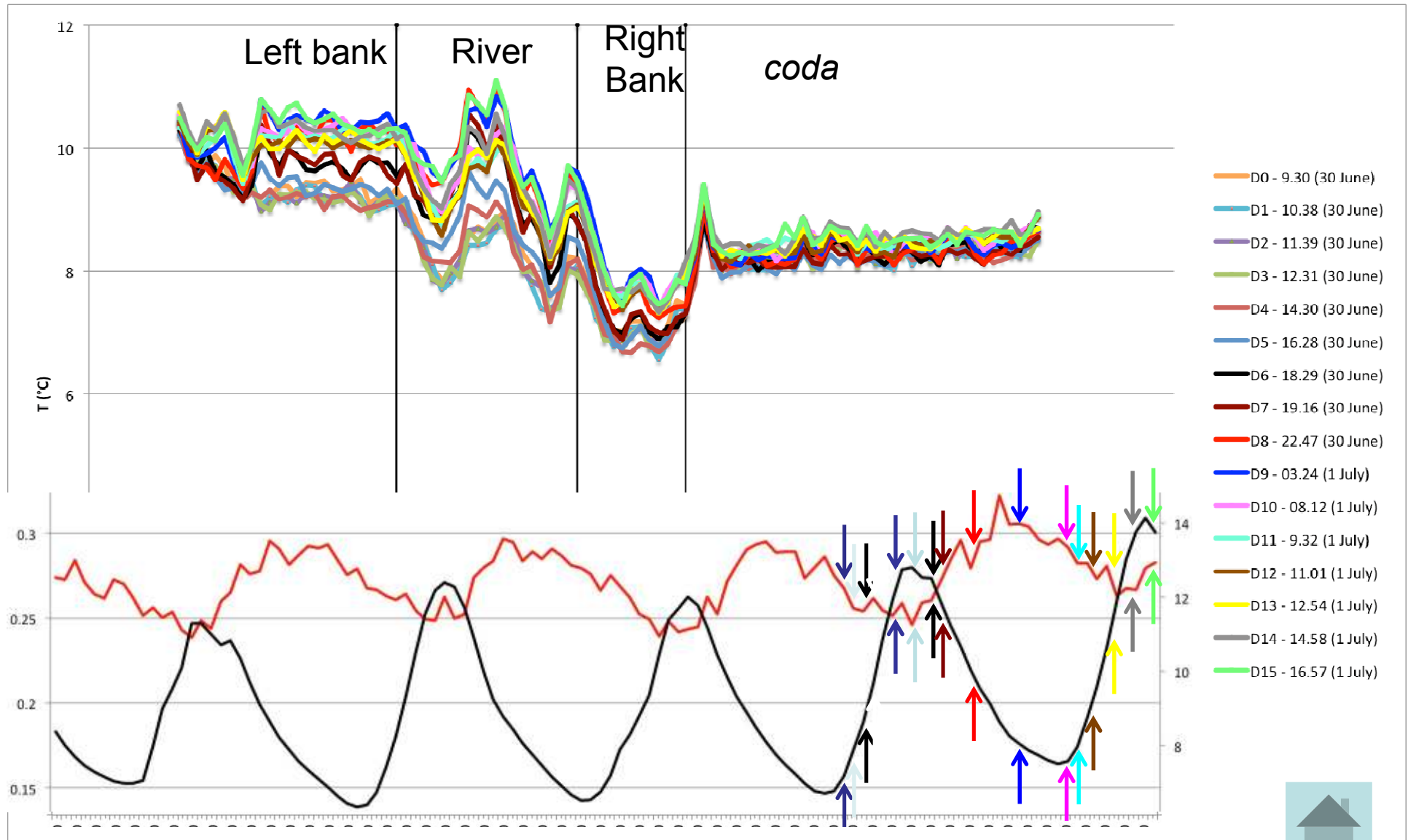
River water level and temperature (27 June – 01 July)



River water level and temperature (27 June – 01 July)



River water level and temperature (27 June – 01 July)



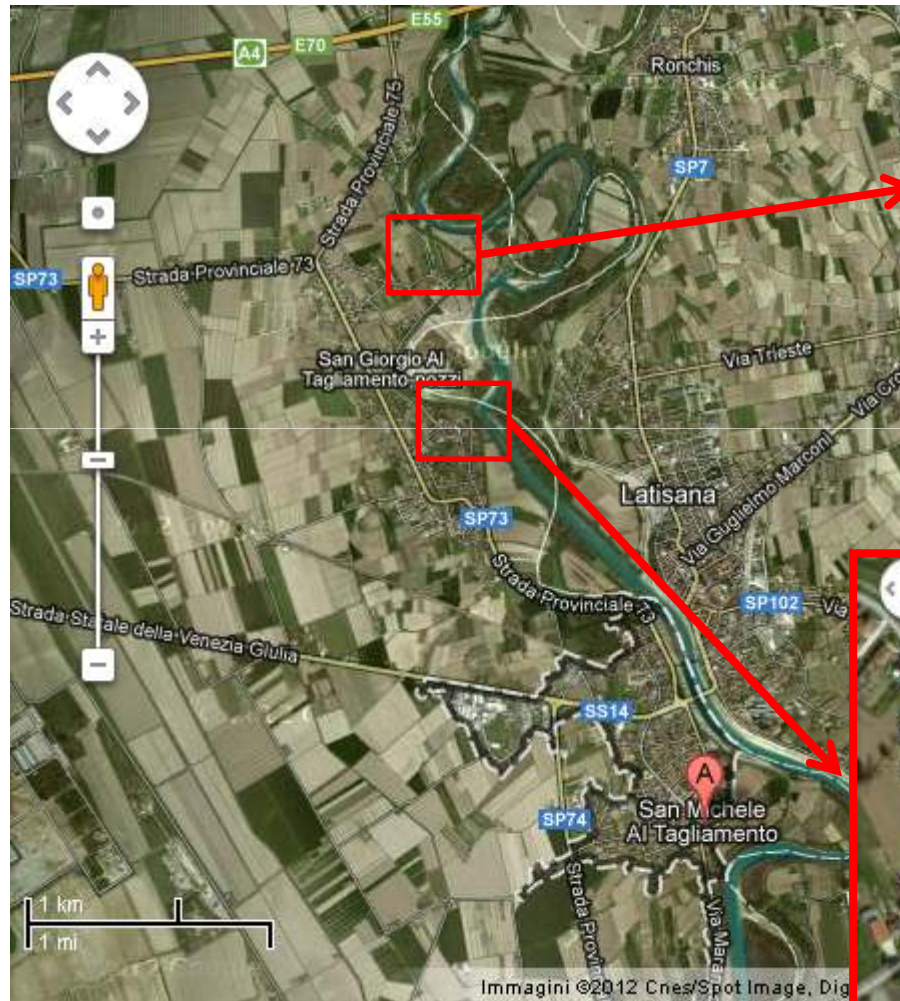
River water level and temperature (27 June – 01 July)

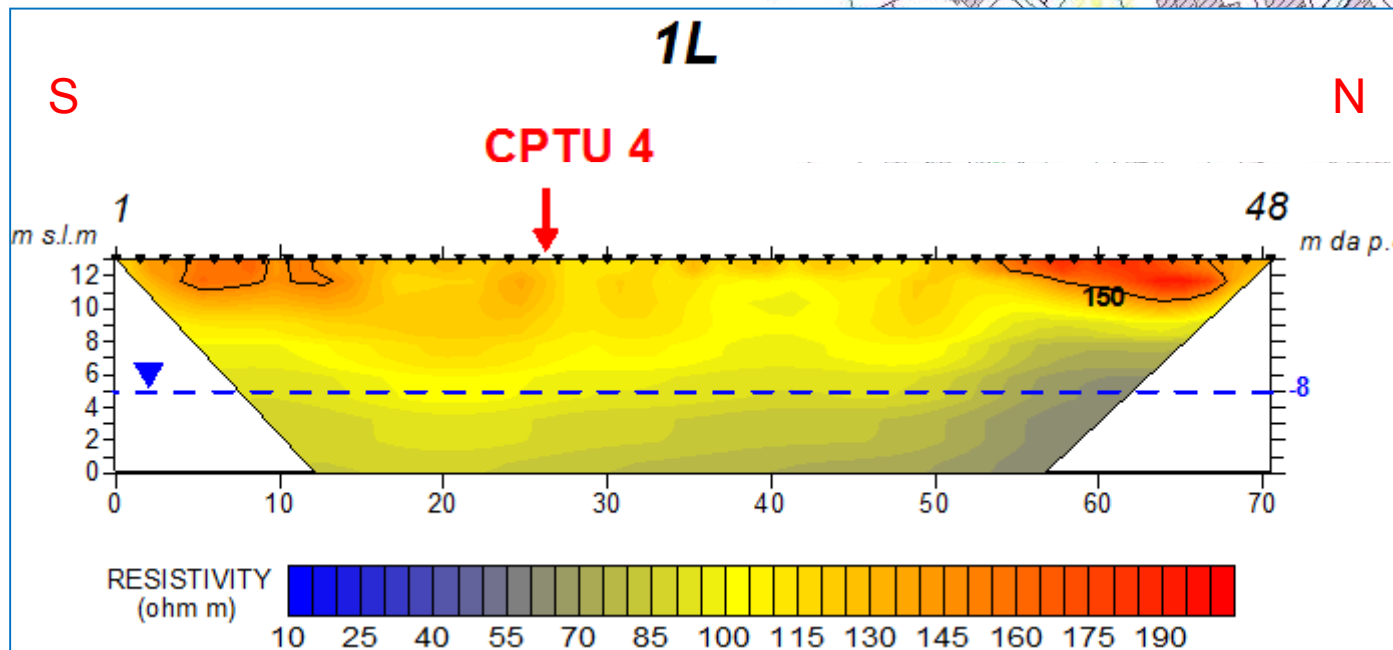
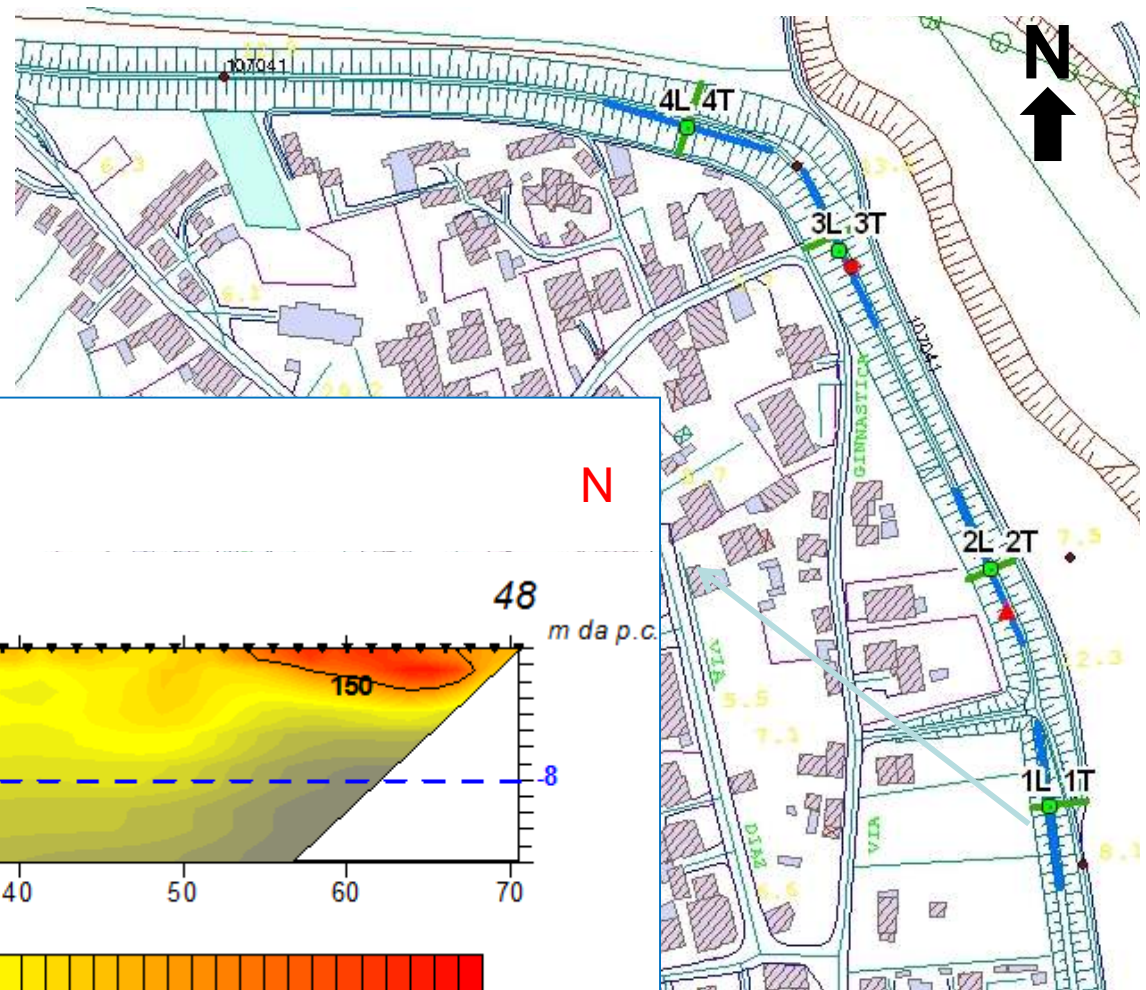






San Michele al Tagliamento



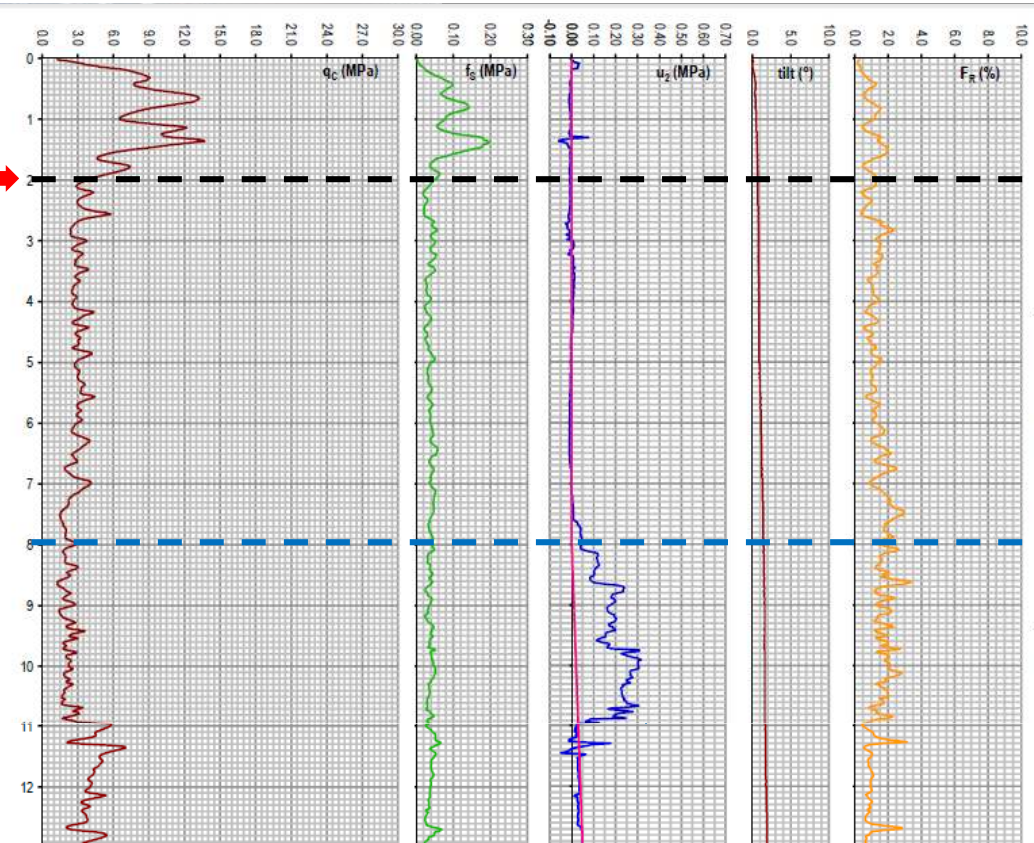


**QUOTA BASE RILIEVO ARGINALE = 8
m.s.l.m.**

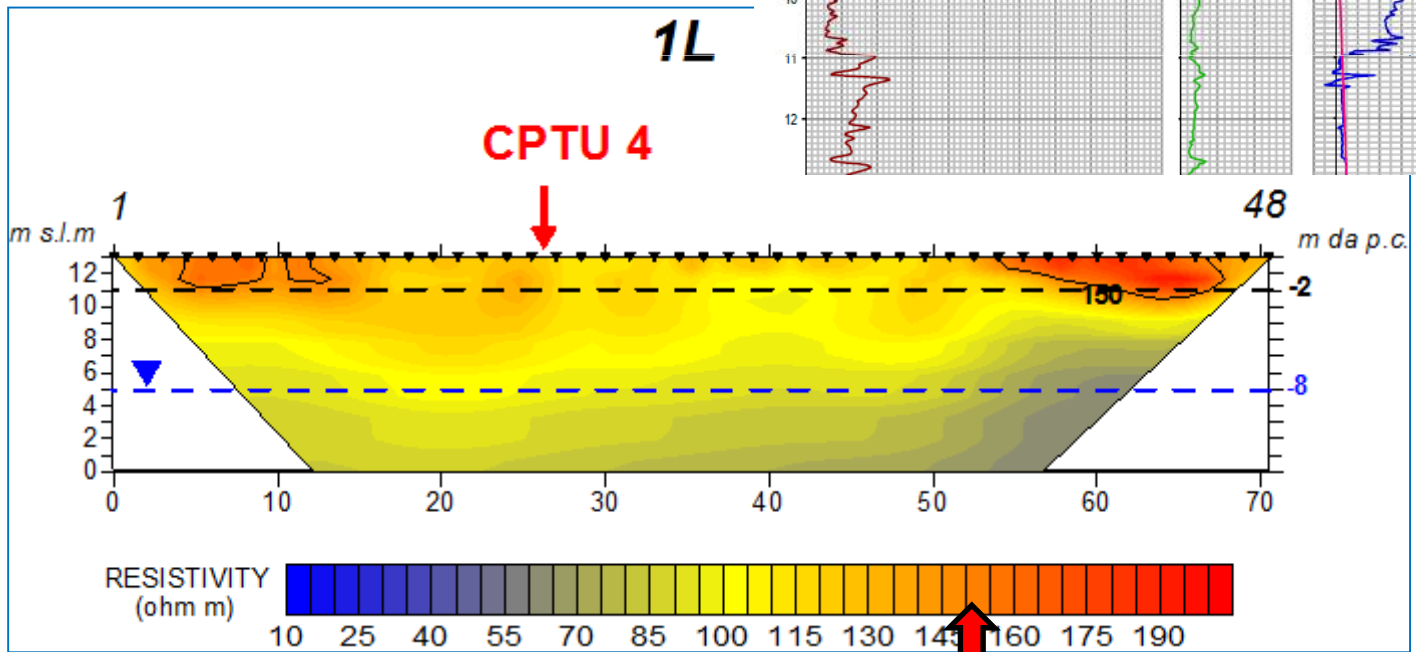


passaggio
limi sabbiosi/
limi debolmente sabbiosi

quota falda



Committente	GENIO CIVILE DI VENEZIA
Cantier/Località	SAN MICHELE AL TAGLIAMENTO (VE)
Prova - Data:	CPTU4 - 14.09.2012



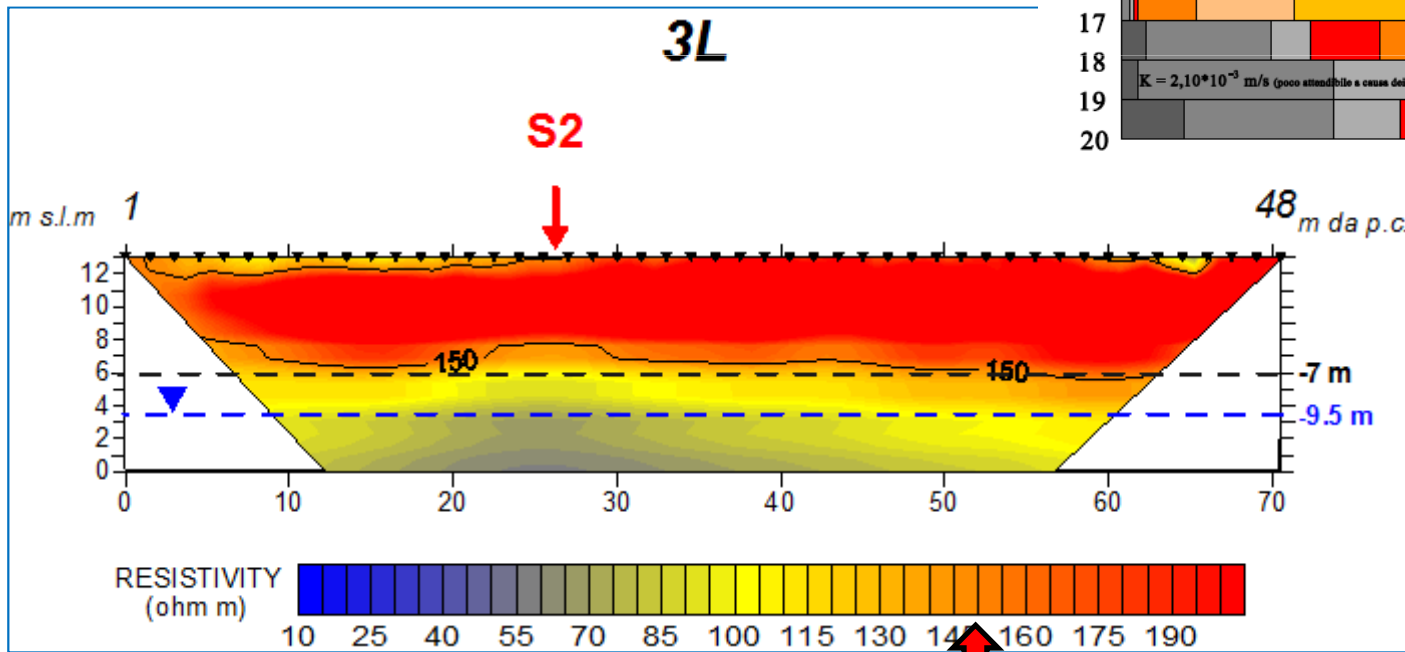
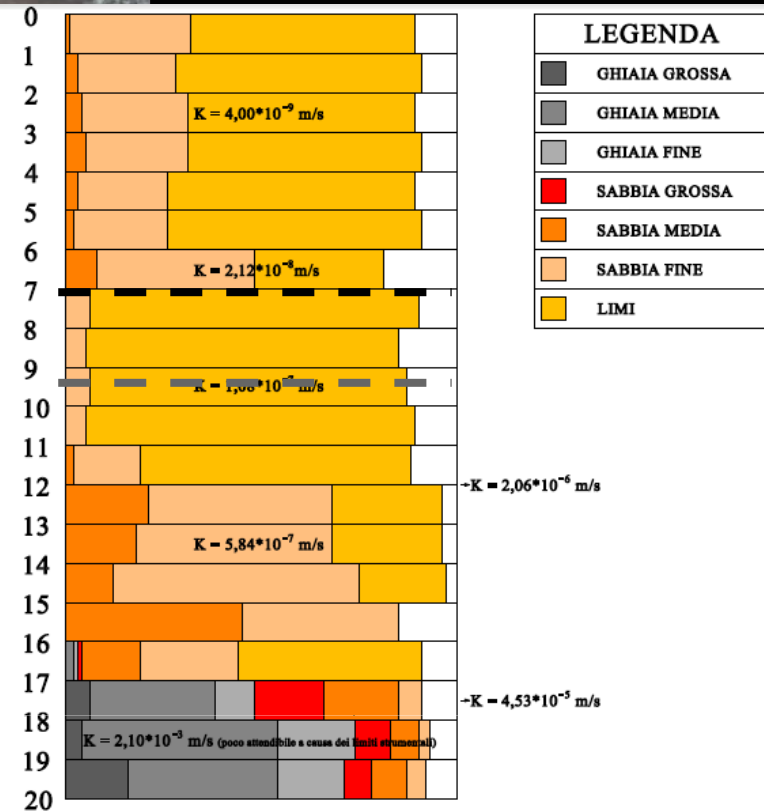
150 Ω m

passaggio limi sabbiosi/ limi deb sabbiosi



passaggio
limi sabbiosi/ limi debolmente sabbiosi

quota falda



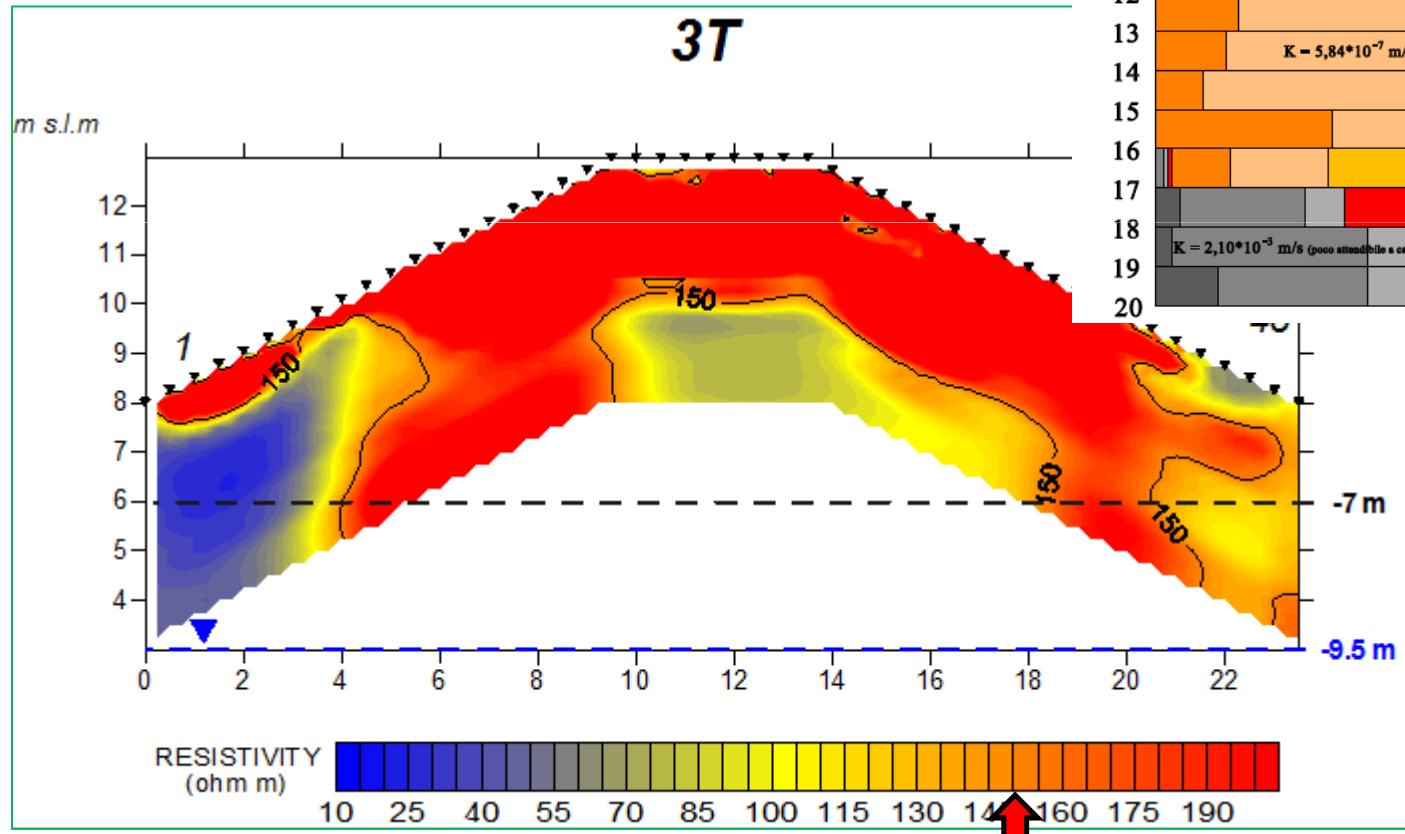
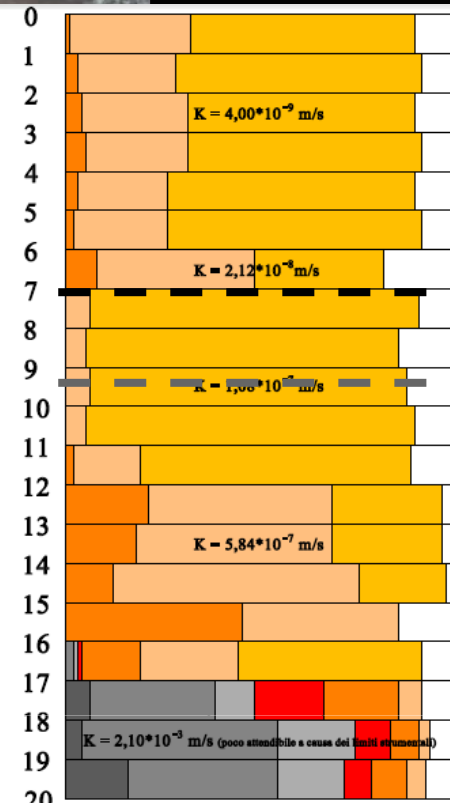
150 Ω m
passaggio limi sabbiosi/ limi deb sabbios



passaggio
limi sabbiosi/ limi debolmente sabbiosi

quota falda

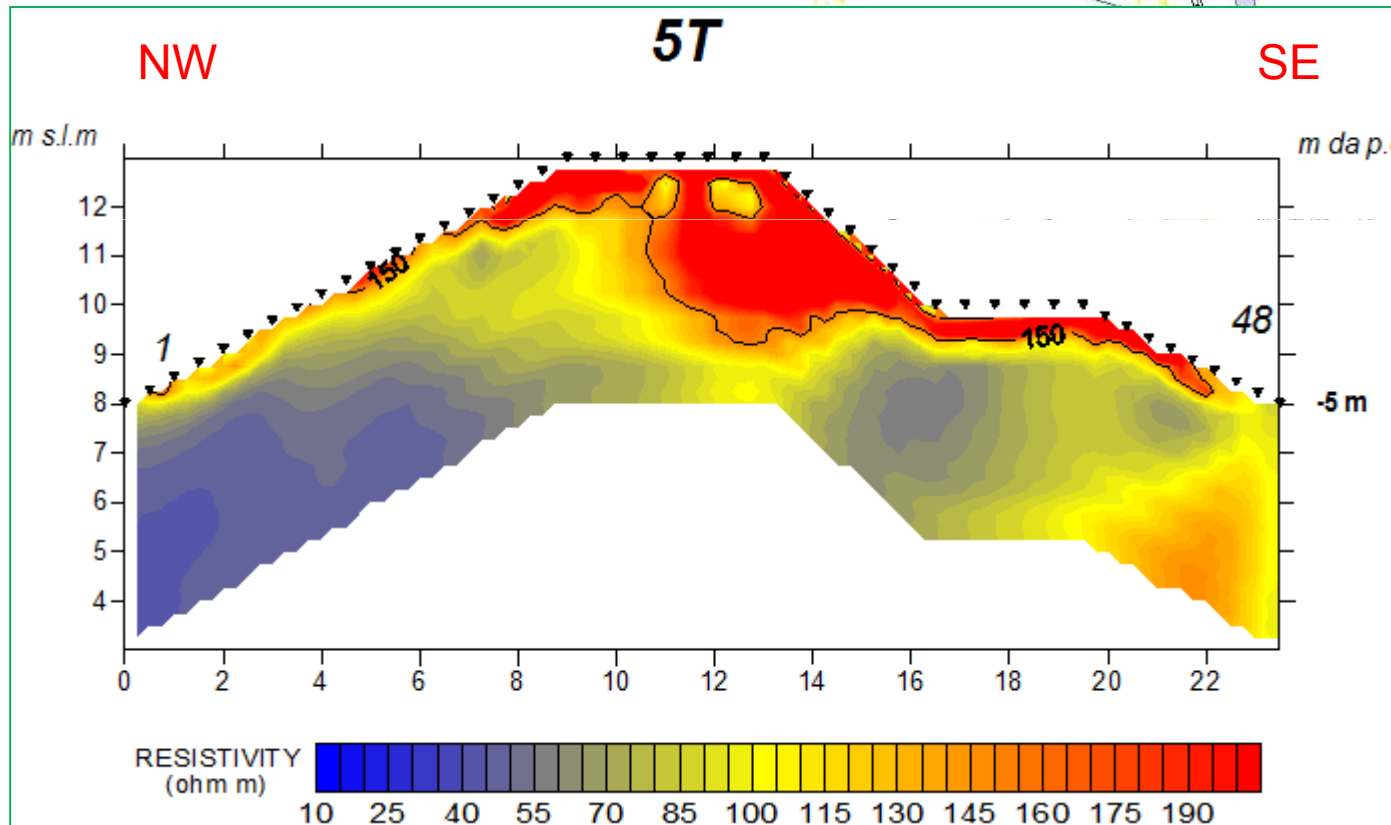
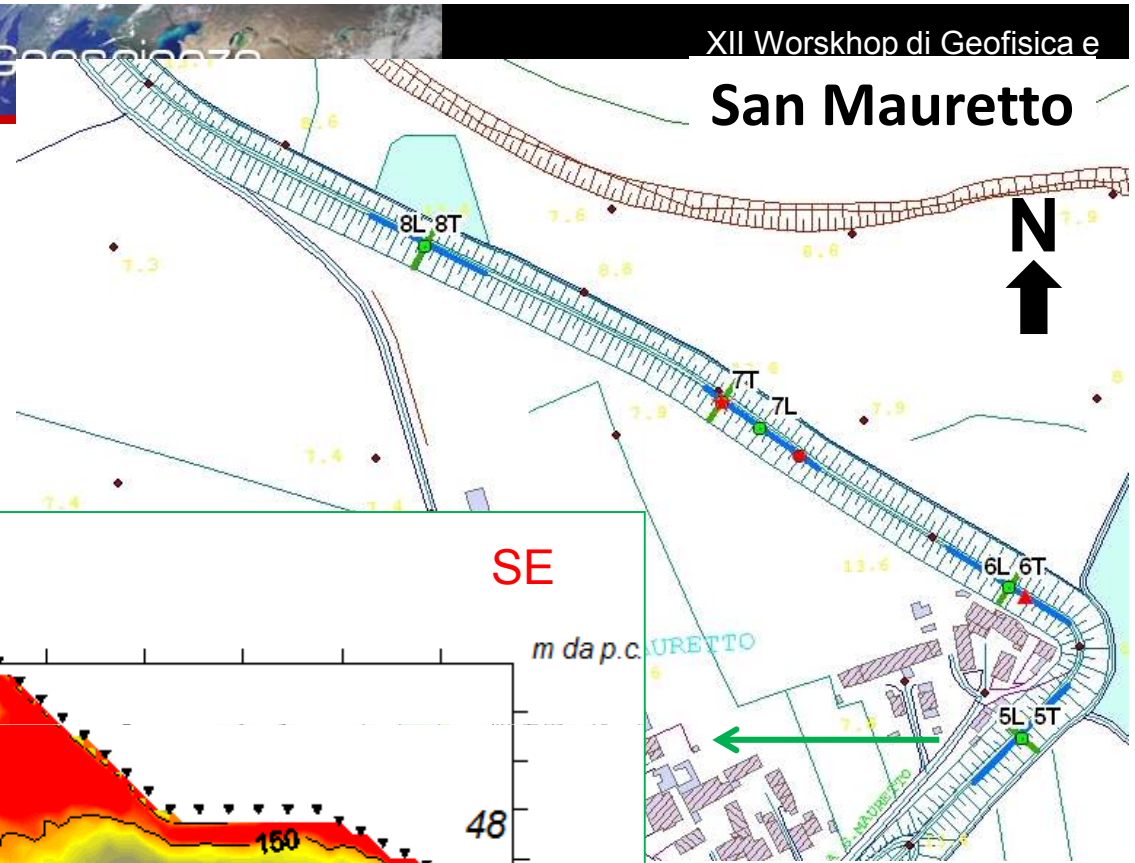
LEGENDA	
	GHIAIA GROSSA
	GHIAIA MEDIA
	GHIAIA FINE
	SABBIA GROSSA
	SABBIA MEDIA
	SABBIA FINE
	LIMI



150 Ω m
passaggio limi sabbiosi/ limi deb sabbios



San Mauretto

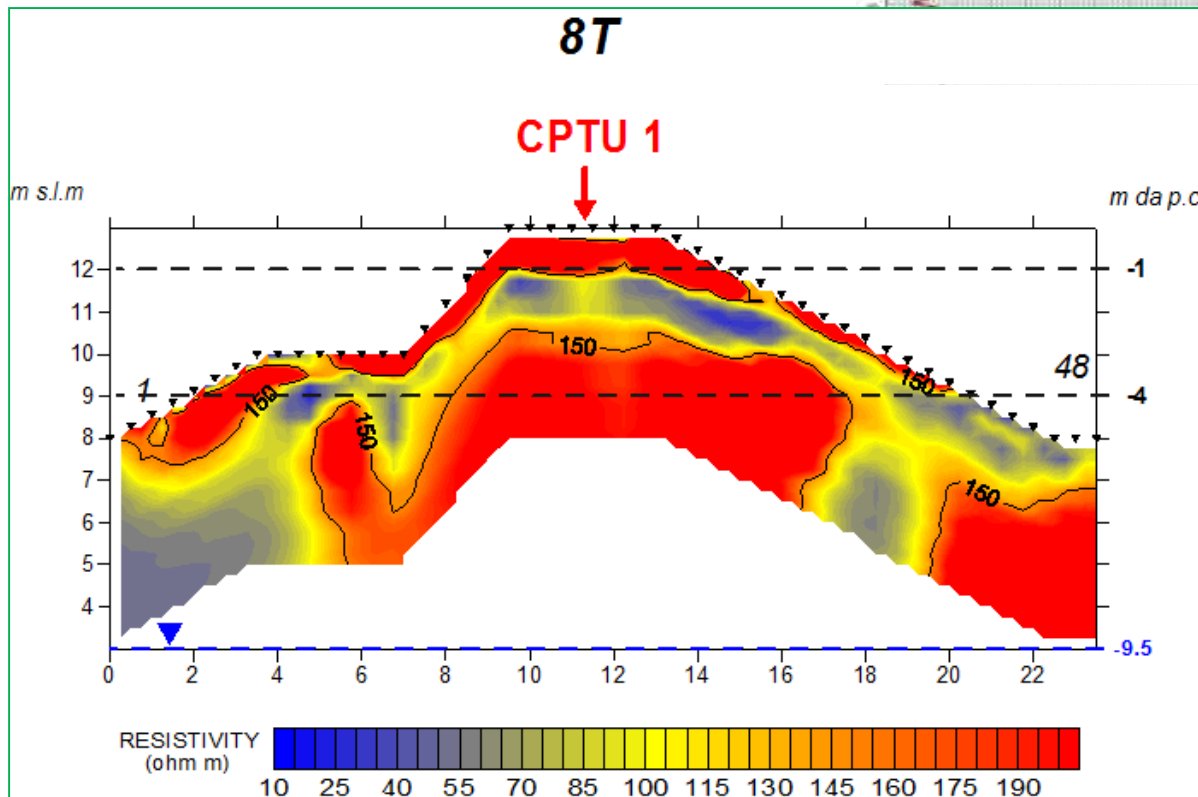
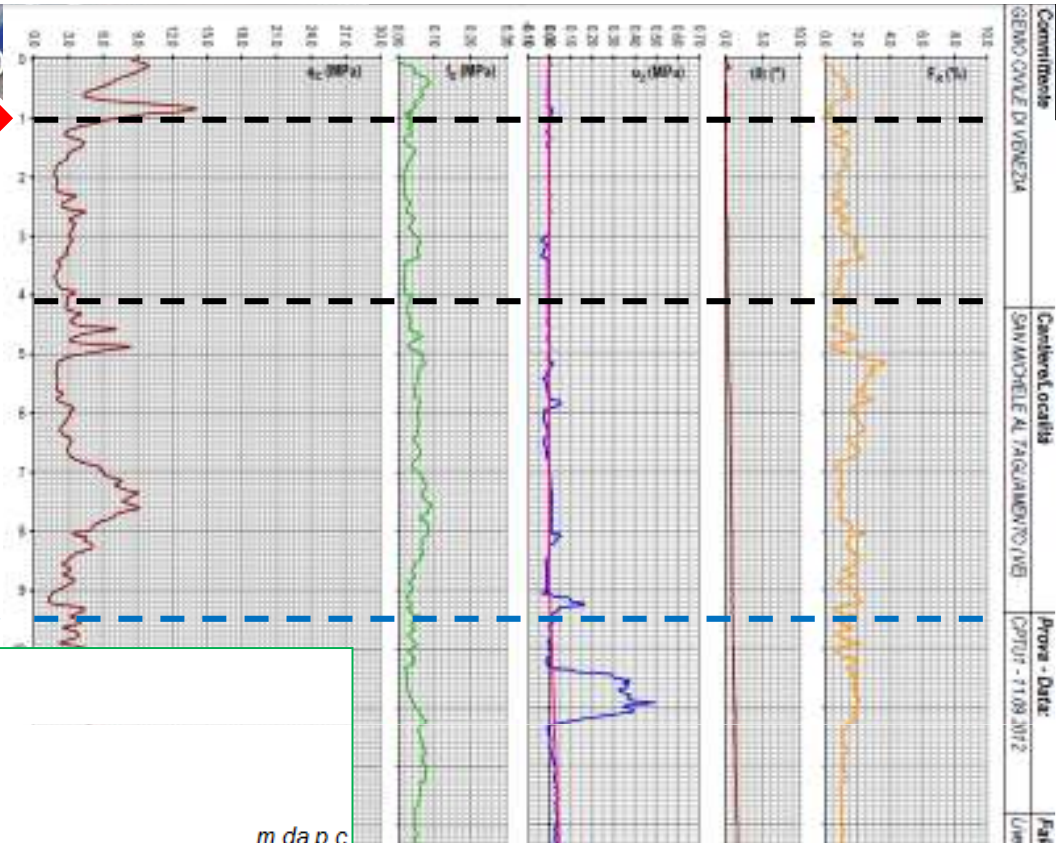


QUOTA BASE RILIEVO ARGINALE = 8
m.s.l.m.



passaggio
limi sabbiosi/
limi debolmente sabbiosi

quota falda →

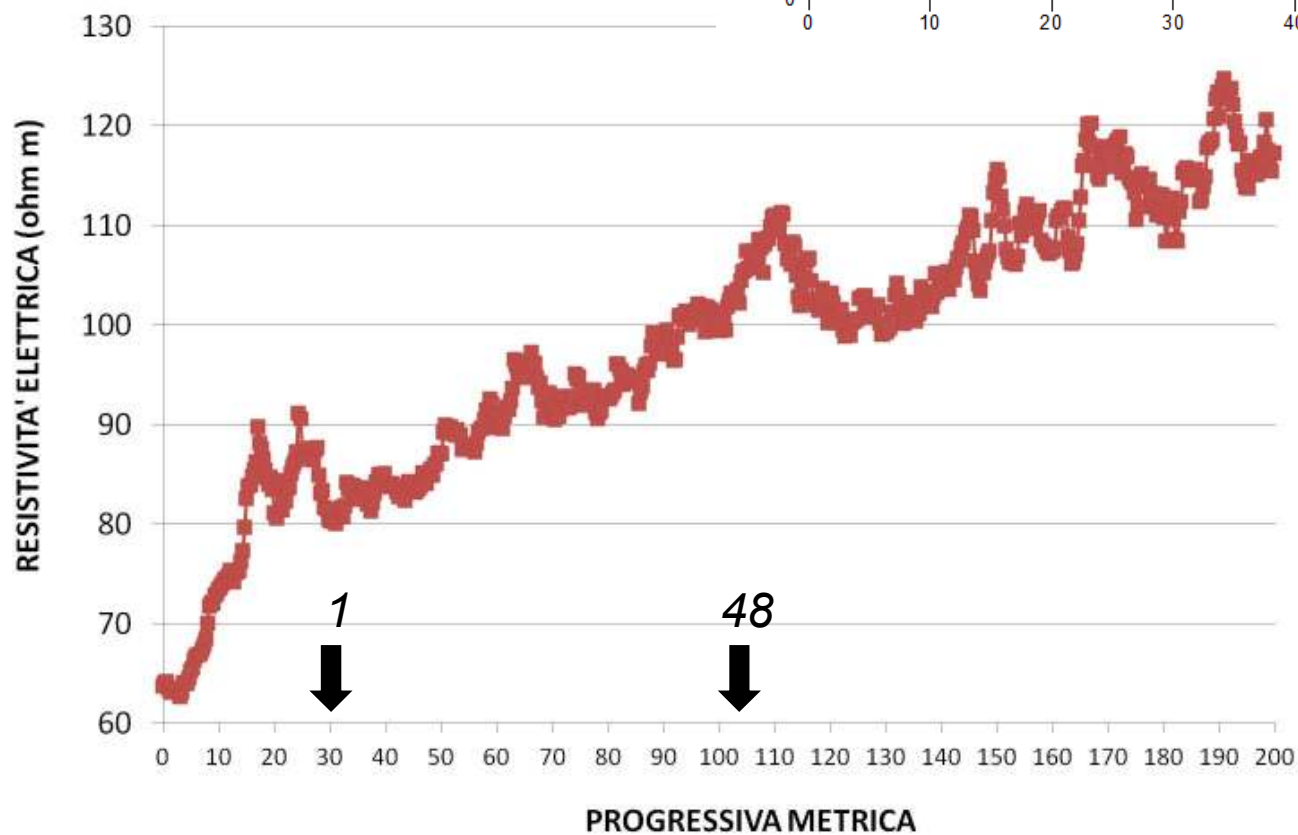
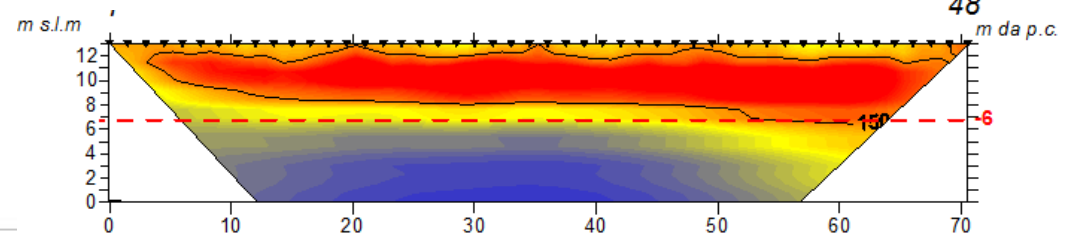
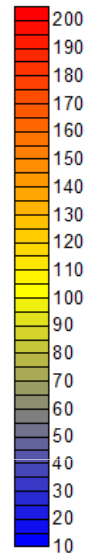




Misure Elettromagnetiche

2L

RESISTIVITY (ohm m)

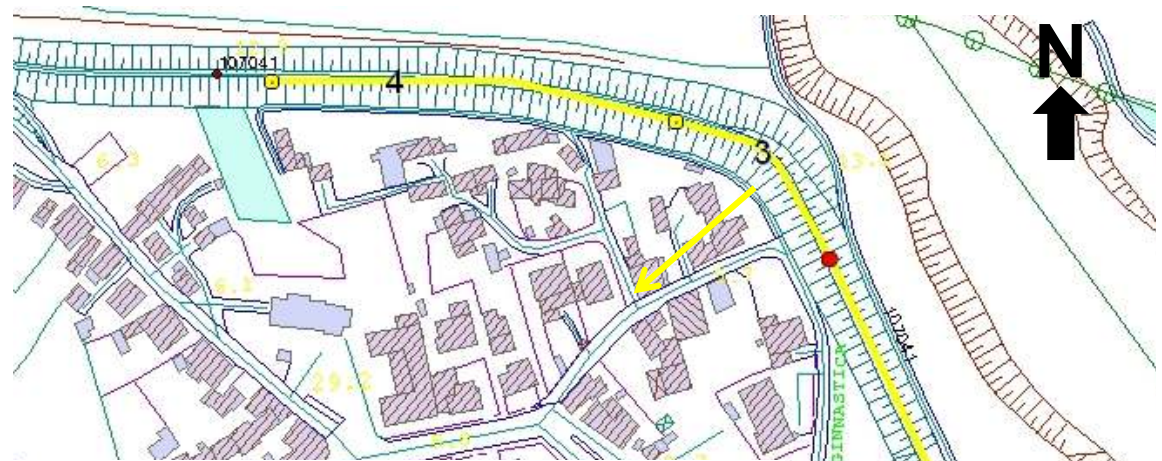


prof. max = 6 m



San Giorgio al Tagliamento

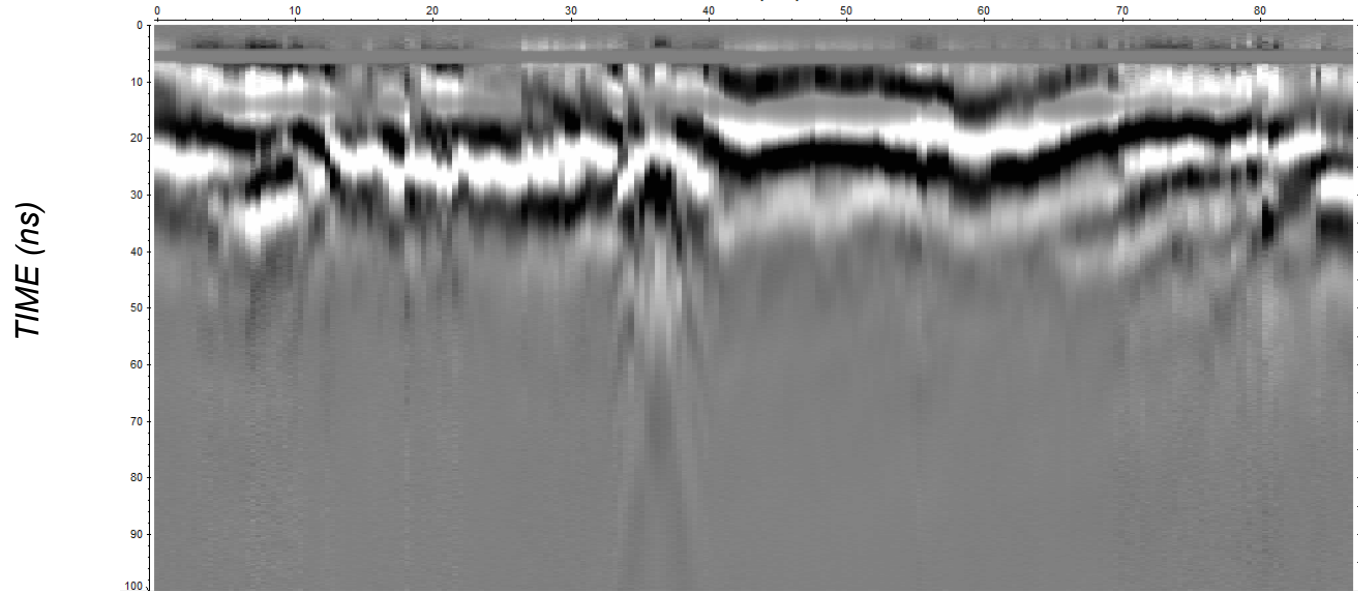
GPR3
 $f = 50$
MHz



S

DISTANCE (m)

N

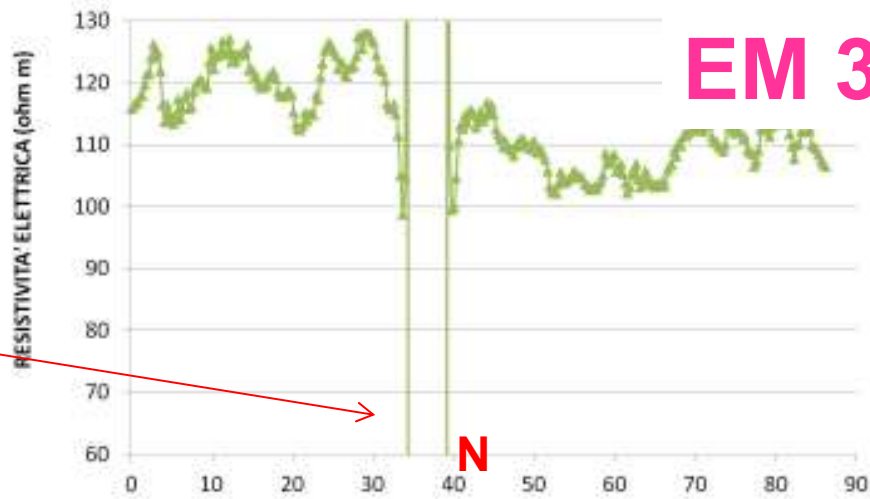


DEPTH ($v=0.08$ m/ns)

$L = 90$ m



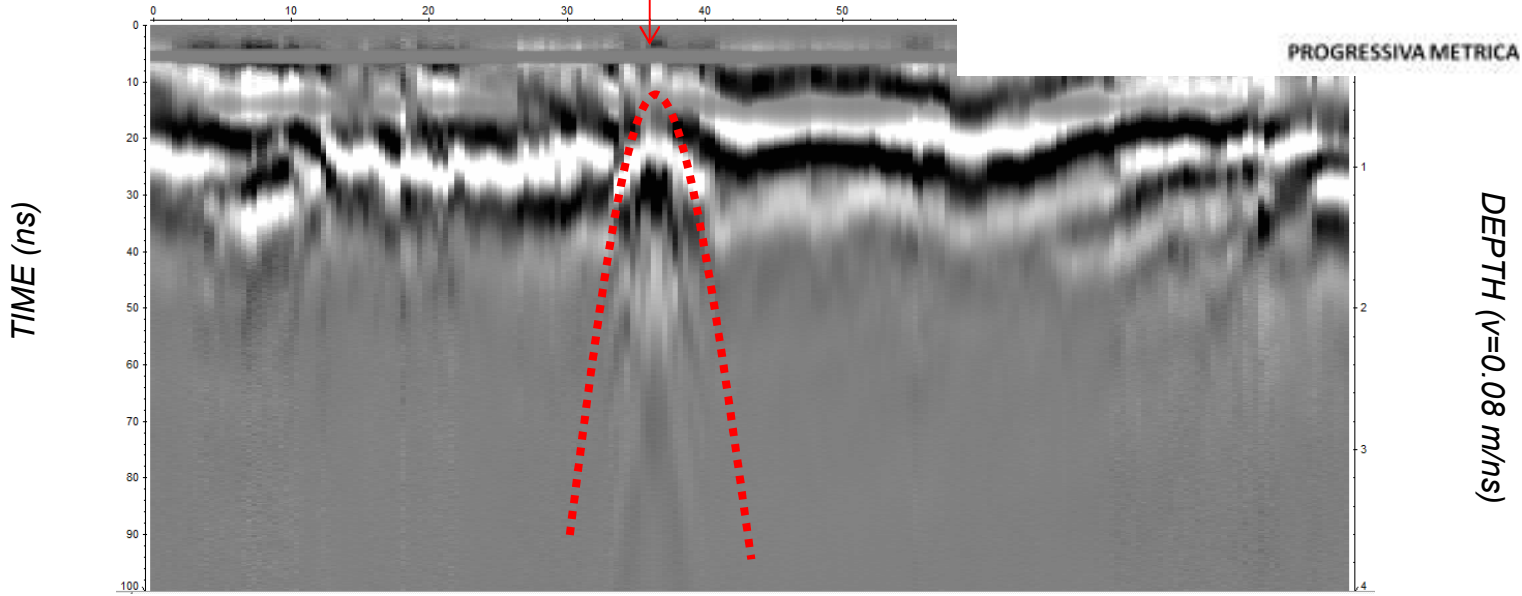
San Giorgio al Tagliamento



Condotta sotterranea

S

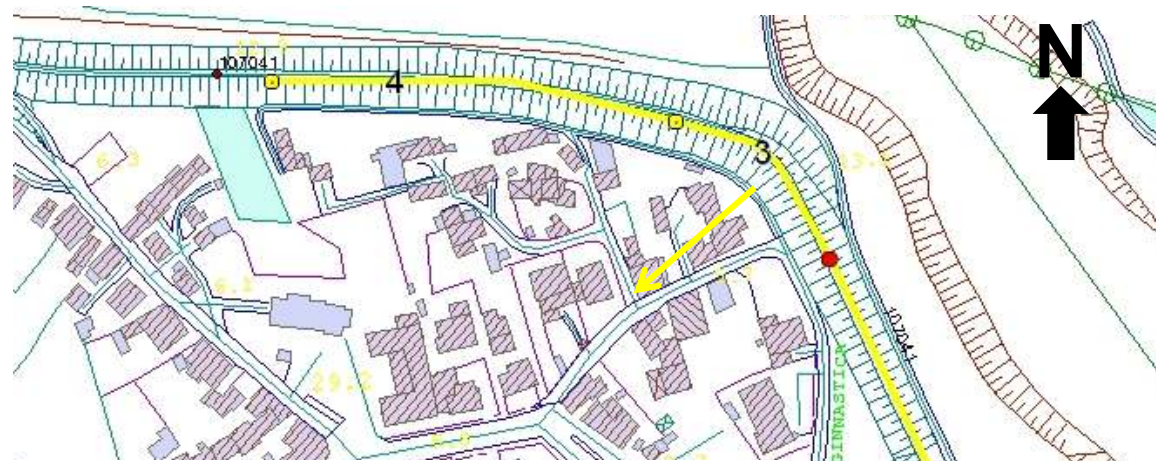
DISTANCE (m)





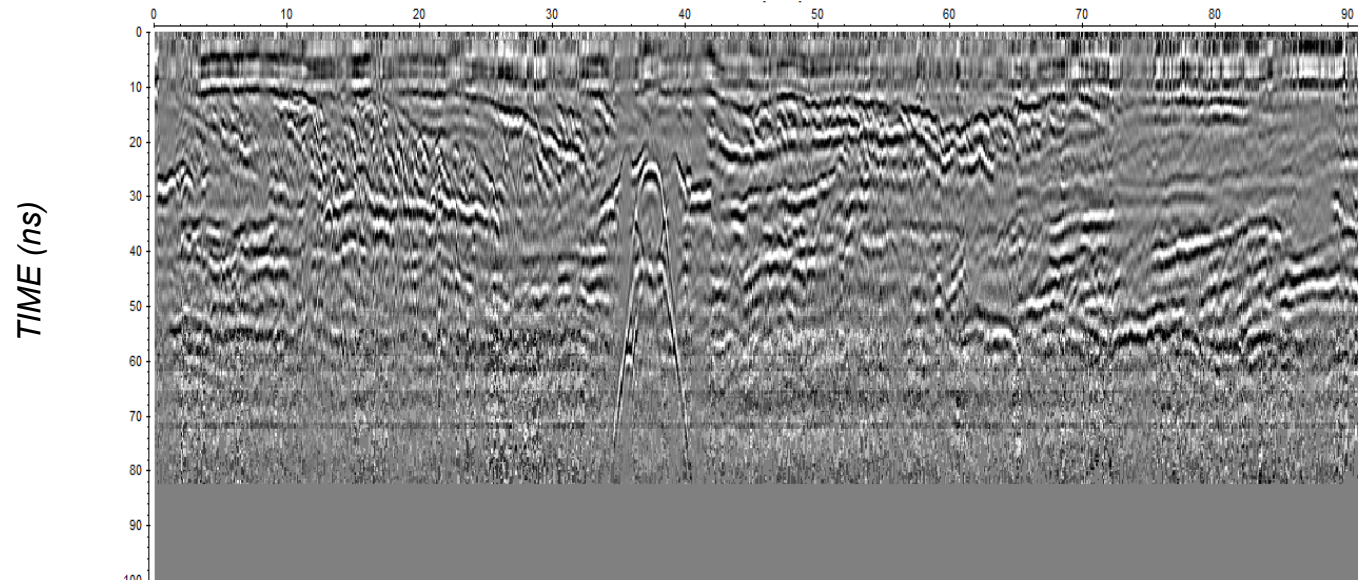
San Giorgio al Tagliamento

GPR3
f = 200 MHz



S

DISTANCE (m)



N

DEPTH ($v=0.08$ m/ns)

L = 90 m







Liquefazione delle sabbie: stima di porosità in sito

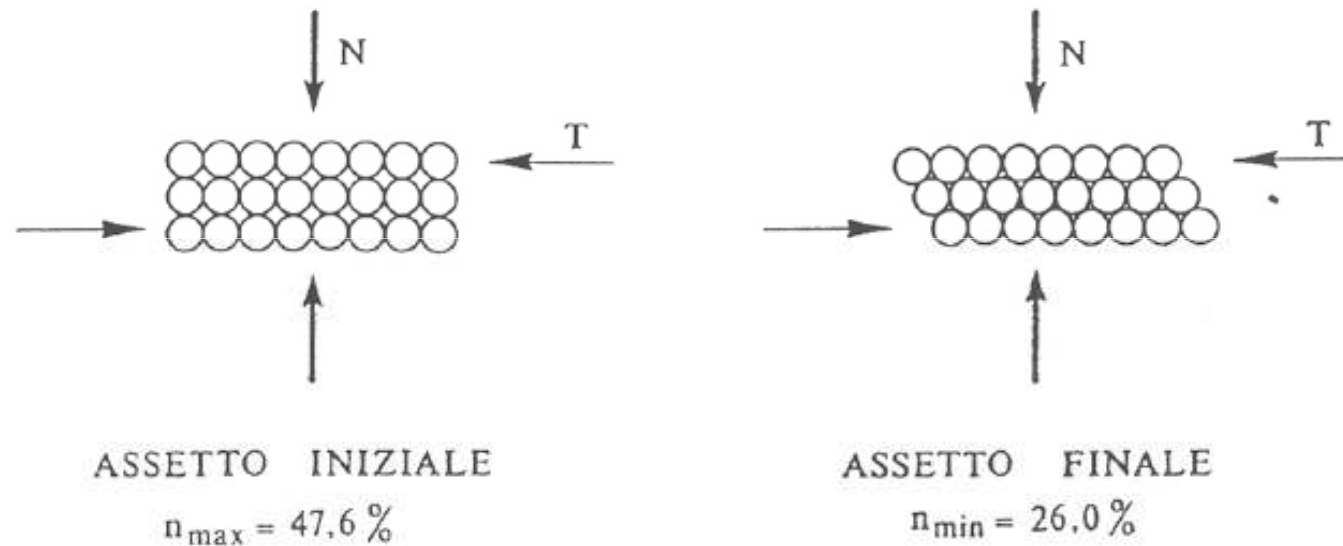
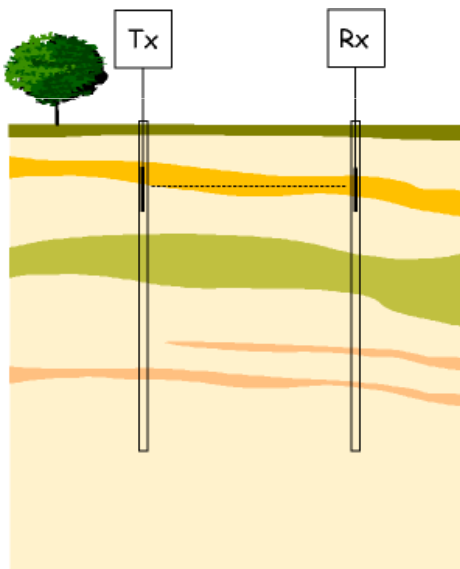


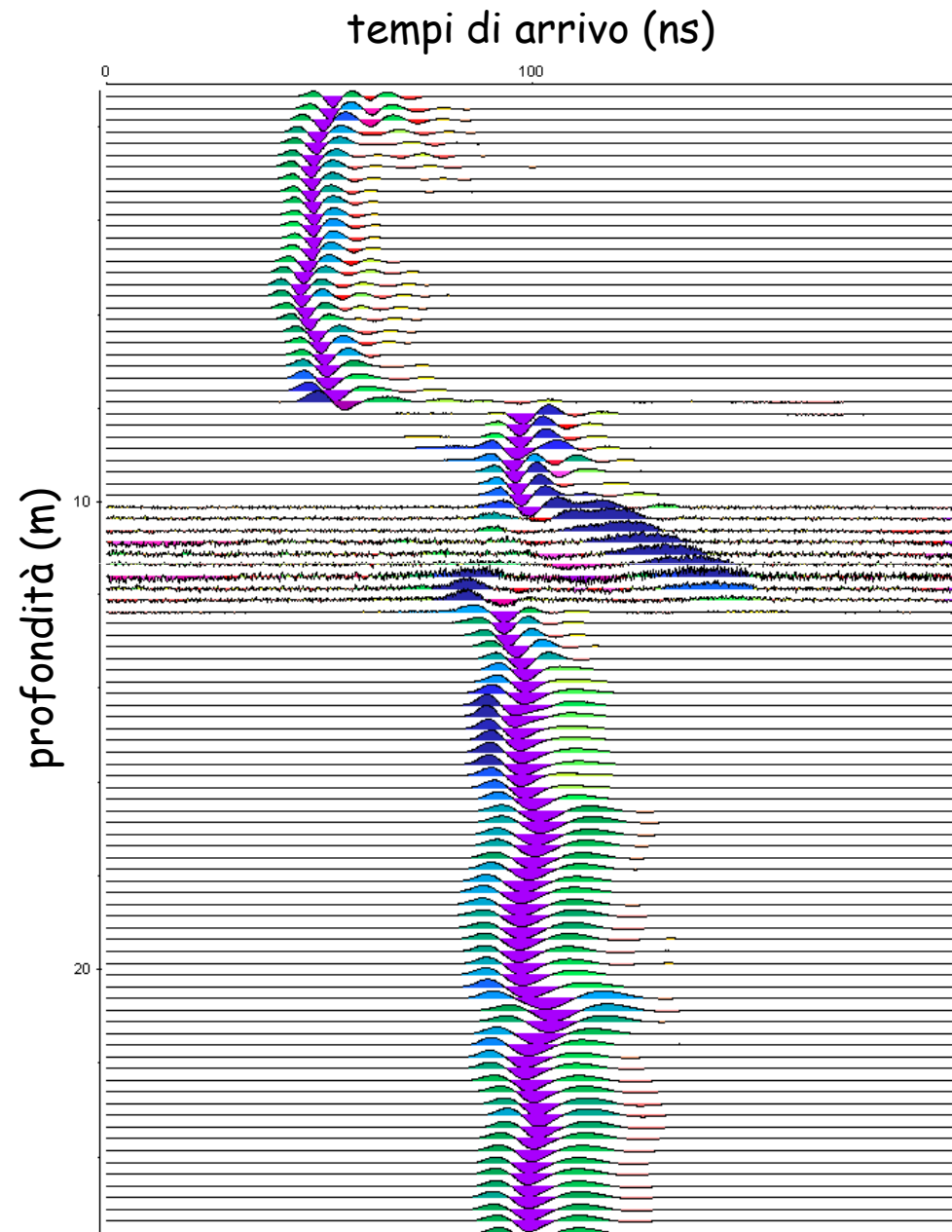
Fig. 6.4 - *Deformazione di un sistema di sfere dallo stato di minimo addensamento a quello di massimo addensamento*



Liquefazione delle sabbie: stima di porosità in sito

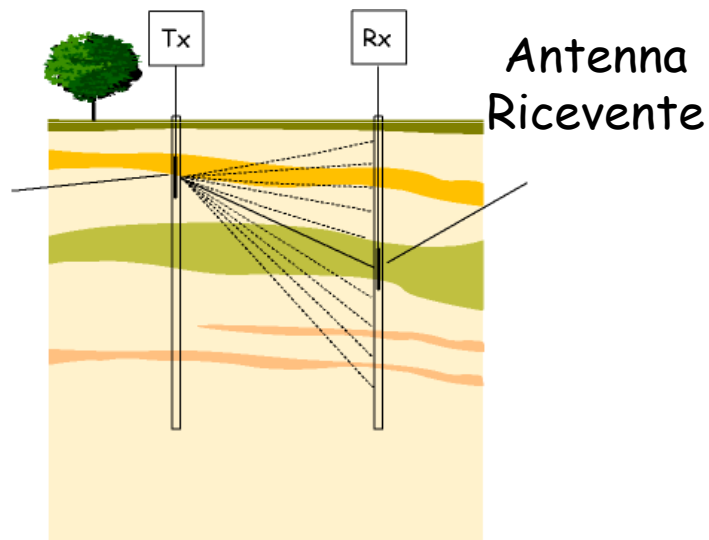


tipica registrazione ZOP

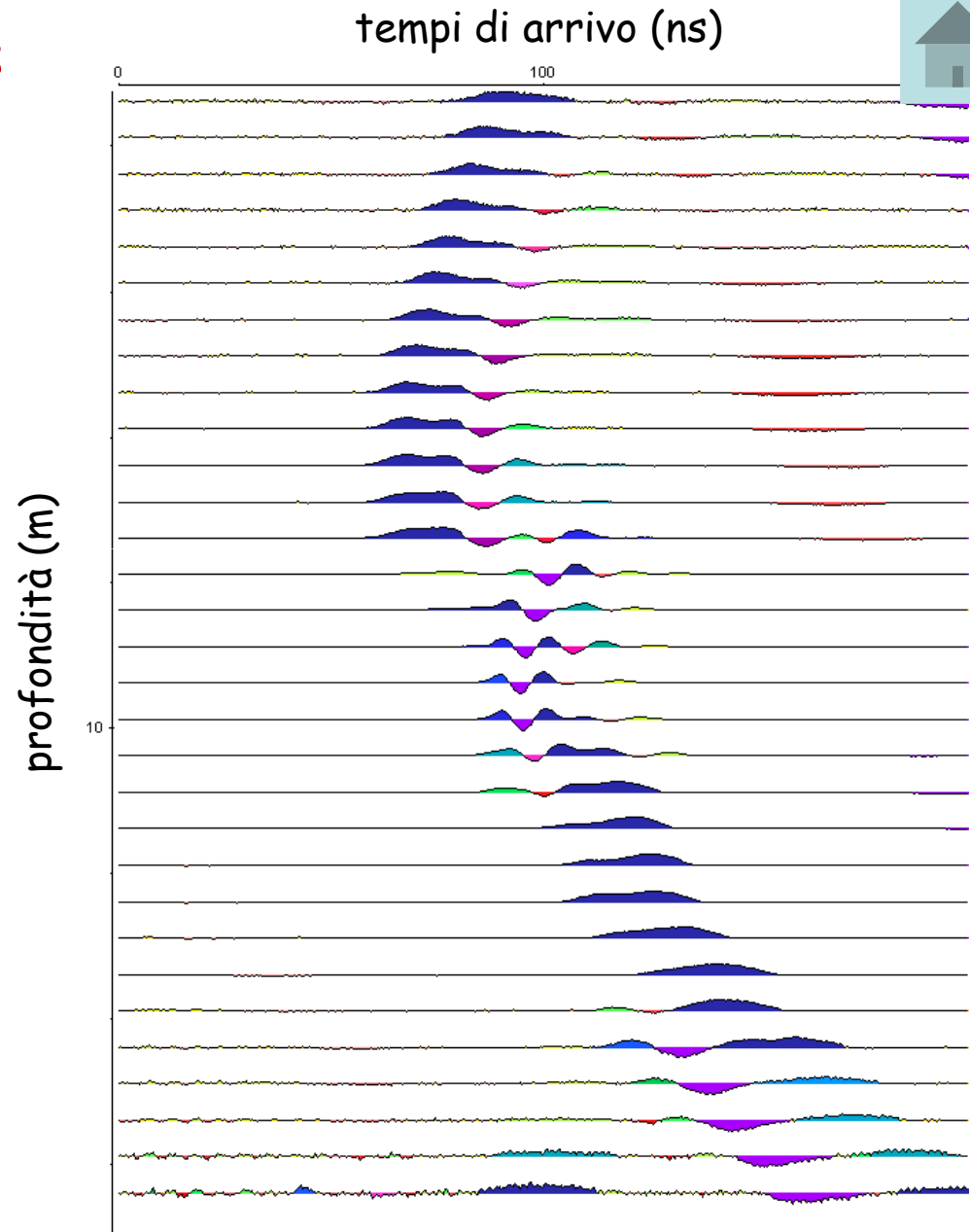




Liquefazione delle sabbie: stima di porosità in sito



tipica registrazione MOG







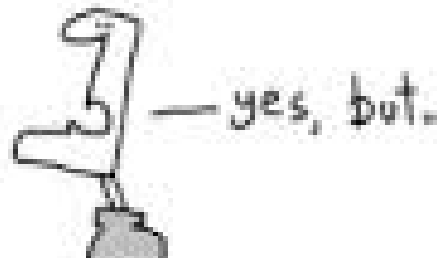
Conclusioni

- ❑ Il modello geotecnico va costruito anche con una **migliore caratterizzazione idraulica dei sistemi con misure in situ.**
- ❑ La **geofisica** può dare un sostanziale aiuto in questo senso, specie perchè è fortemente **affetta dalle caratteristiche statiche e dinamiche** del suolo e sottosuolo.
- ❑ Questo fatto, se adeguatamente riconosciuto, offre un enorme **contenuto di informazione sui processi e sulle strutture.**
- ❑ L'informazione ottenibile si massimizza con **misure ripetute nel tempo e integrazione con modelli predittivi dei fenomeni stessi.**



Why is geophysics still so rarely used to its full capacities?

GREAT IDEAS ALTER THE
POWER BALANCE IN RELATIONSHIPS.
THAT'S WHY GREAT IDEAS ARE
INITIALLY RESISTED.



hugh



Ackn. for slides:
Gregory Street
Past-President
Australian Society of
Exploration Geophysicists

**"You've written a bold and innovative proposal.
Unfortunately, it challenges the status quo and
that can jeopardize my job."**

Ringraziamenti: persone

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Mario Putti

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etc etc





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iSOIL

ModelPROBE

CLIMB

GLOBAQUA

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PRIN 2007

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Finanziamenti industriali:

Eni SpA

etc..

