UNIVERSITÀ DEGLI STUDI DI PARMA

Monitoraggio geoelettrico per il rischio idrogeologico
Progetto Tech-Levee-Watch e Progetto Dilemma
Milano, 19 febbraio 2019

Fast scanning delle arginature

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Tech Levee Watch

Outline

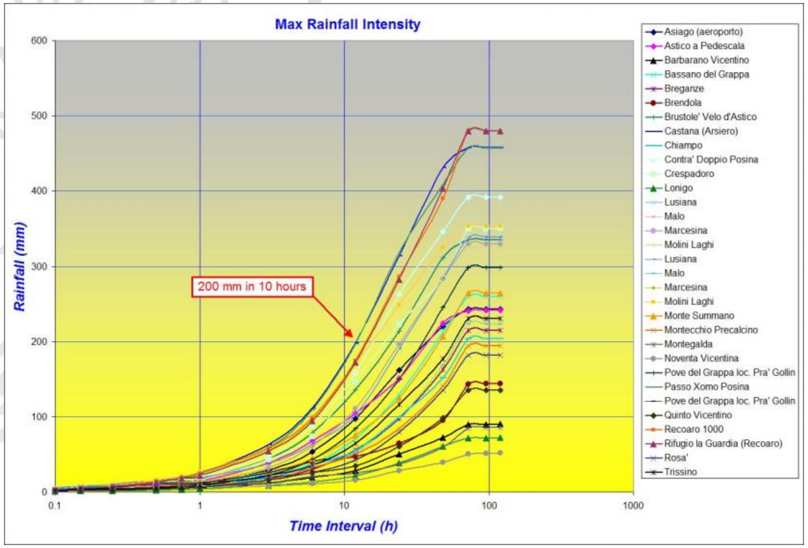
- Introduzione e motivazioni;
- Il sistema di *imaging* geofisico per il *Fast Scanning*;
- Analisi dei dati e validazione;
- Risultati da alcuni casi di studio e discussione;
- Conclusioni.

Introduction and motivations

It's well established how levee failures occurring during floods cause severe damages to agriculture, industry, buildings and infrastructures.

In the last years in Europe as well as in many other regions of the world have been observed several unexpected events with maxima of rainfall intensity of **hundreds** of **mm in few hours.**

… recent studies (Jongman et al., 2014) indicate how the frequency of extreme events could also double within 2050 …



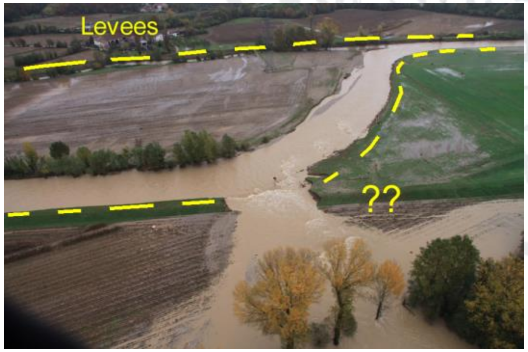
Introduction and motivations

The social cost of these events could be very high. As an example these are the figures of a major event in Northern Italy. Most of the damages were caused by levee collapses.

- Area: 14,000 square km;
- Involved Municipalities: 131;
- Involved Population : 500,000;
- Casualties: 2;
- Farm animal losses: 230,000;
- Major road closed: 55;
- Flooded area: 140 square km;

- Landslides : 51
- Floodings: 29
- **Levee collapses : 15**

Damages (rough estimate):
450 Millions of Euro
mostly due to levee failures



Reasons for levee Collapse ?

In recent years several pilot projects, in different countries, were then undertaken to image the internal composition of levees.

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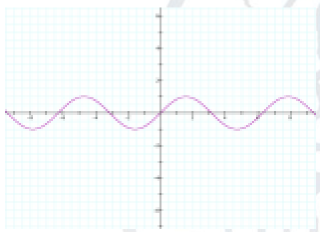
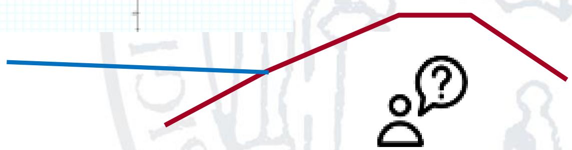
Tech Levee Watch

Veneto 2010, Secchia 2014, Enza 2017, Ardenza 2017

Introduction and motivations

Nelle pianure Italiane ci sono migliaia di km di rilevati arginali la cui origine risale spesso al medioevo e sulle quali ci sono informazioni molto scarse … se non nei tratti storicamente problematici …



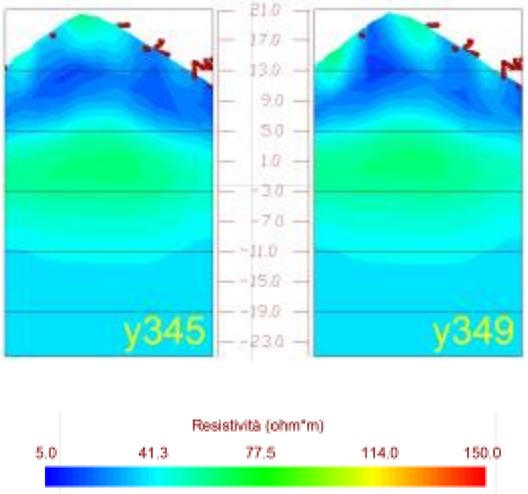


La risposta di queste strutture di difesa alle piene storiche spesso non è un'informazione sufficiente per valutare grado di rischio.

La possibilità di investigare in modo <u>celere</u> ed <u>economico</u> lunghi tratti arginali per identificare segmenti potenzialmente critici è quindi un contributo fondamentale per la mitigazione del rischio da alluvione.

Introduction and motivations

La geofisica è sicuramente adatta per lo scopo.



Tra le diverse tecniche applicabili allo studio dei rilevati arginali la tomografia elettrica (Chambers et al., 2013) è quella che per capacità risolutiva, logistica e *sensitivity* produce i migliori risultati. La tecnica, per tempi e costi, non è però utilizzabile come strumento diagnostico estensivo.

Max prod per un 3D a 2 cavi paralleli → 0.7-1.0 km/gg
4 cavi paralleli → 0.5 km/gg

~2.5/5.0*10^3 Euro/km

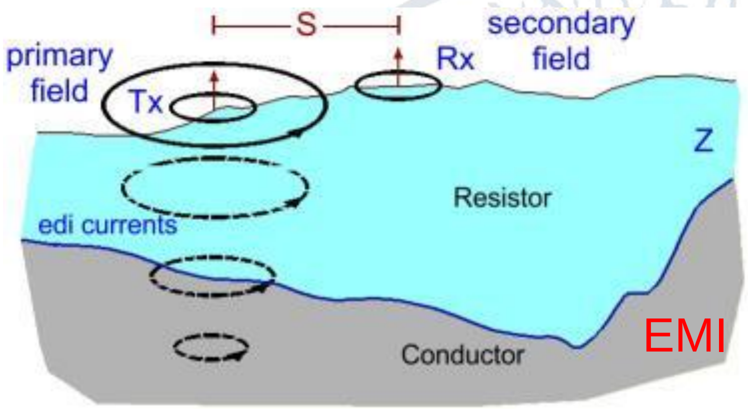
I metodi applicabili in modalità cinematica che sino ad ora hanno avuto il maggiore consenso in ambito scientifico (Hayashi , 2014; Niederleithinger et al., 2012) sono quelli basati sull'induzione elettromagnetica (EMI – *ElectroMagnetic induction*) e sulla propagazione di onde elettromagnetiche (GPR – *Ground Penetrating/Probing Radar*).

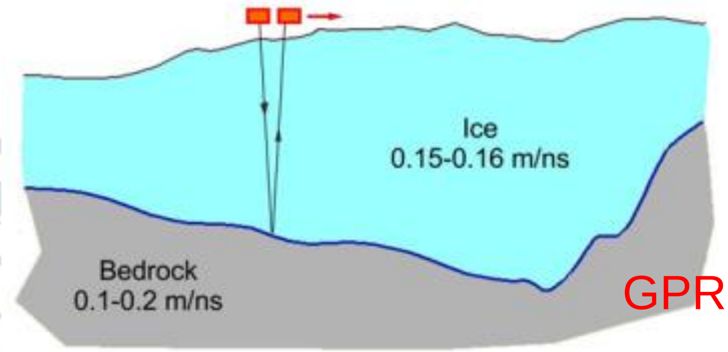
Max prod per un doppio rilievo → 10-15 km/gg

~0.5*10^2 Euro/km

The dual geophysical imaging system

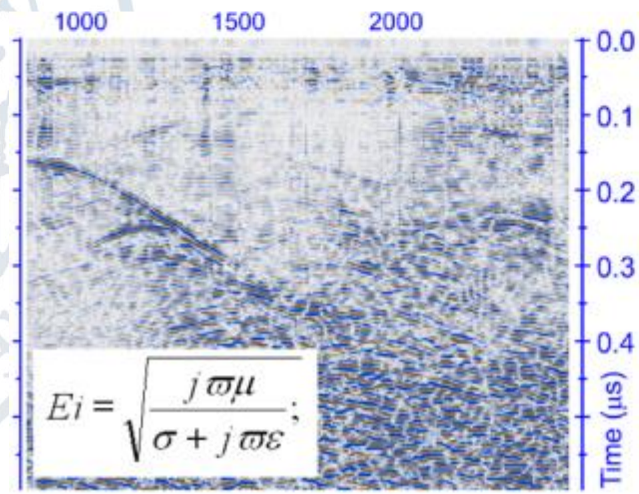
Teoria dei metodi (1)





$$\sigma = \frac{4}{\omega \mu_0 S^2} \left(\frac{Hs}{Hp} \right);$$

$$\omega = 2\pi f;$$



$$Ei = \sqrt{\frac{j\varpi\mu}{\sigma + j\varpi\varepsilon}};$$

<u>FDEM</u> induction measures the amplitude of the magnetic component of an induced EM field (Hs) caused by a primary EM field. This value, under certain assumptions, could be related to the apparent conductivity (σ) of the subsurface.

<u>GPR</u> propagates polarized waves that are reflected at dielectric interfaces (ε, μ, σ).

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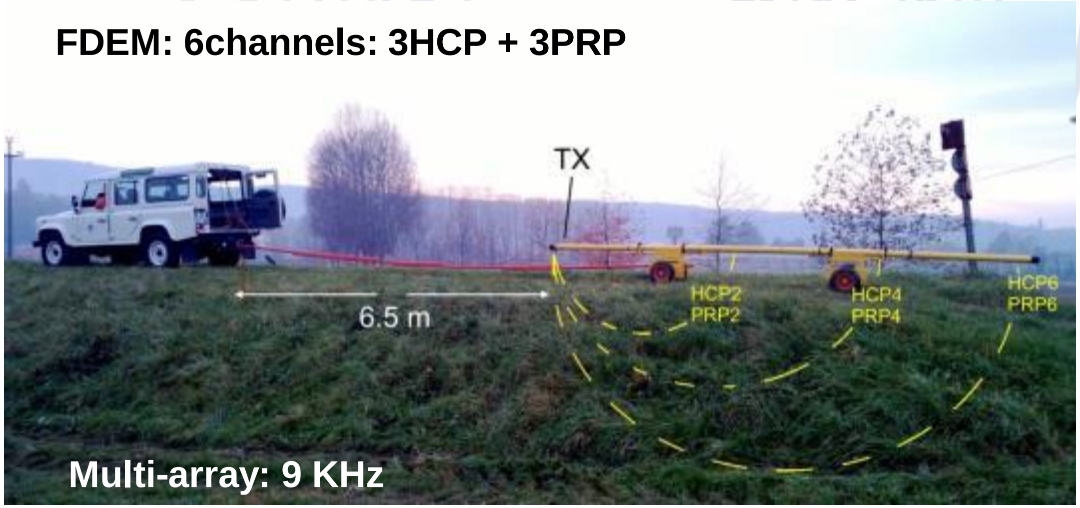
The dual geophysical imaging system

Multifrequency
&
Multi-array
1/2 m
1-16 KHz

Several methods and geophysical techniques were tested and a dual imaging system, based on multi-channel GPR and multi-array FDEM, proved to be the most flexible and efficient approach.



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Depth of investigation issues

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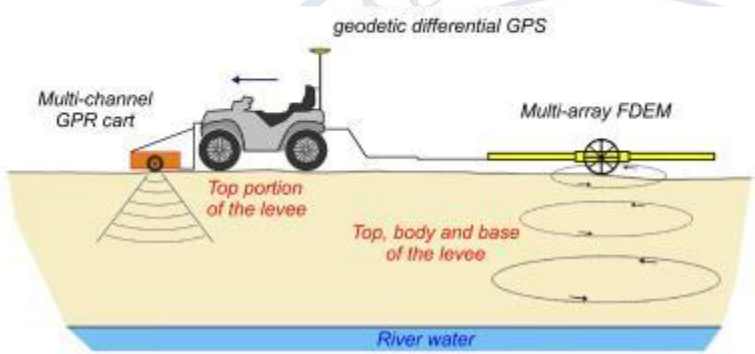
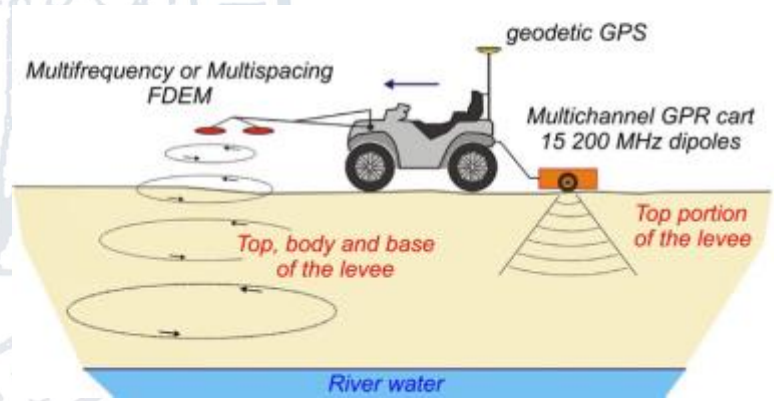
The dual geophysical imaging system

The general idea behind this system is its cost-effectiveness based on the capability of scanning several kilometres per day of river embankments with an adequate degree of resolution.



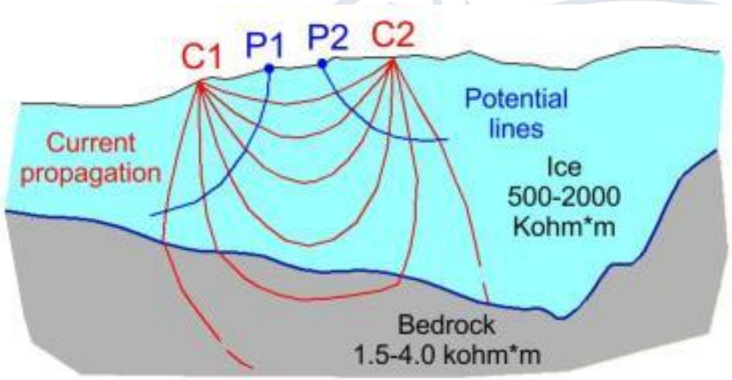


The anomalies mapped via dynamic scanning could be further investigated in a later phase by mean of 2D or 3D electrical resistivity tomography (ERT).

The dual geophysical imaging system

Teoria dei metodi (2)

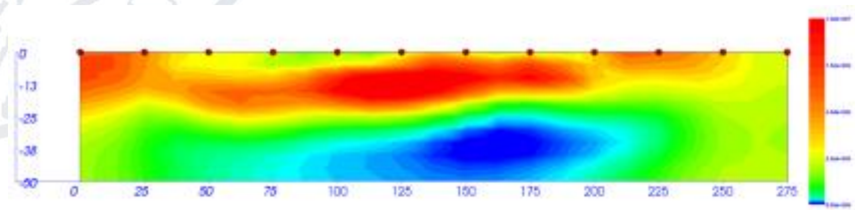
The ERT method uses the classical electrical quadrupole, automatically sequenced, to generate apparent resistivity maps later inverted to true resistivity profiles (2D) or volumes (3D).



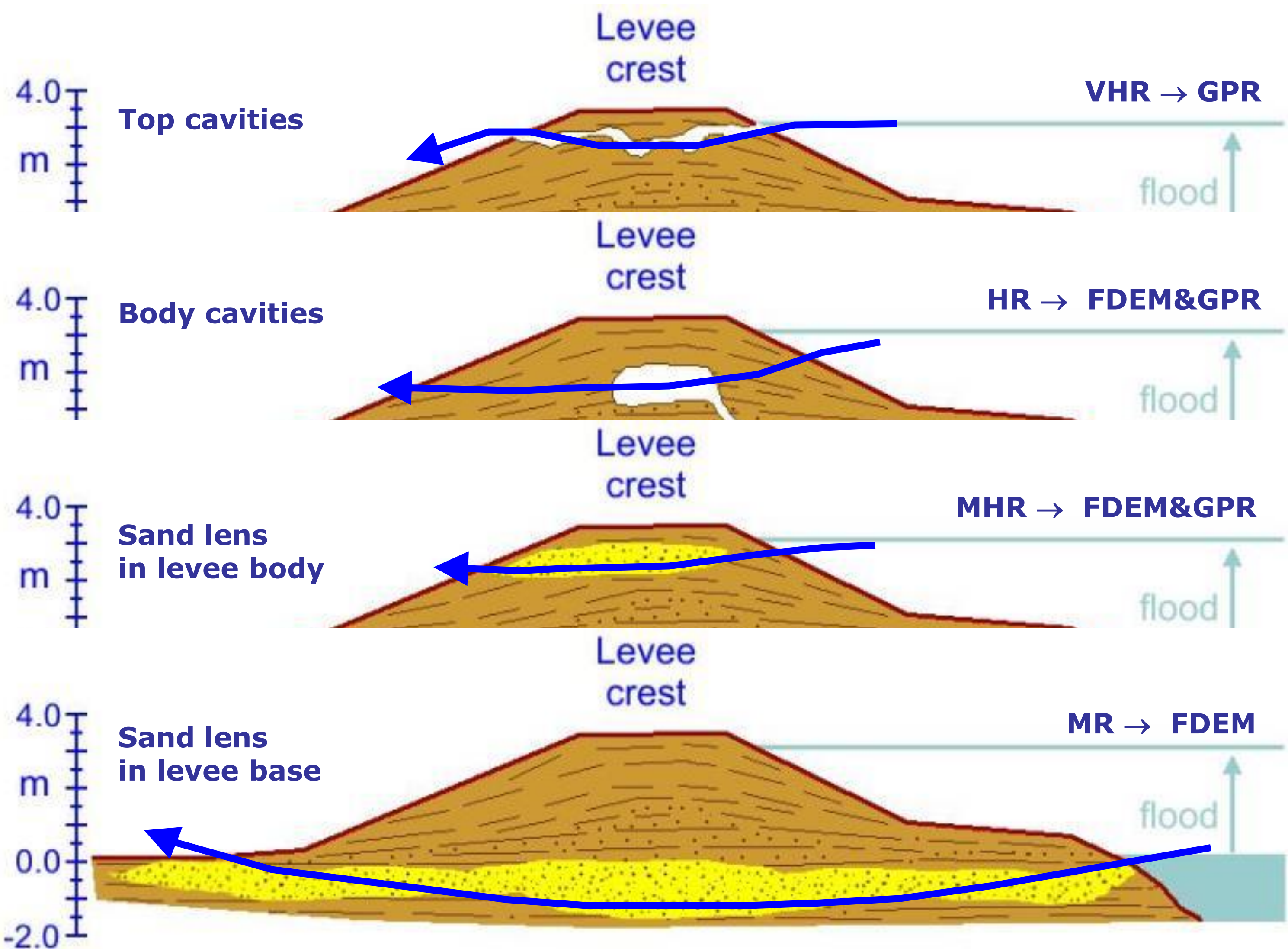
Depth of investigation is controlled by distance C1-C2.

The method measures the resistivity (ρ) of the subsurface

$$\rho = \frac{2\pi\Delta V}{I}\left(\frac{1}{C1P1} - \frac{1}{C2P1} - \frac{1}{C1P2} + \frac{1}{C2P1}\right)^{-1};$$



The dual geophysical imaging system: the targets



Altre cause di instabilità arginale: (1) sormonto e dilavamento; (2) disseccamento e fratturazione; (3) discontinuità ...

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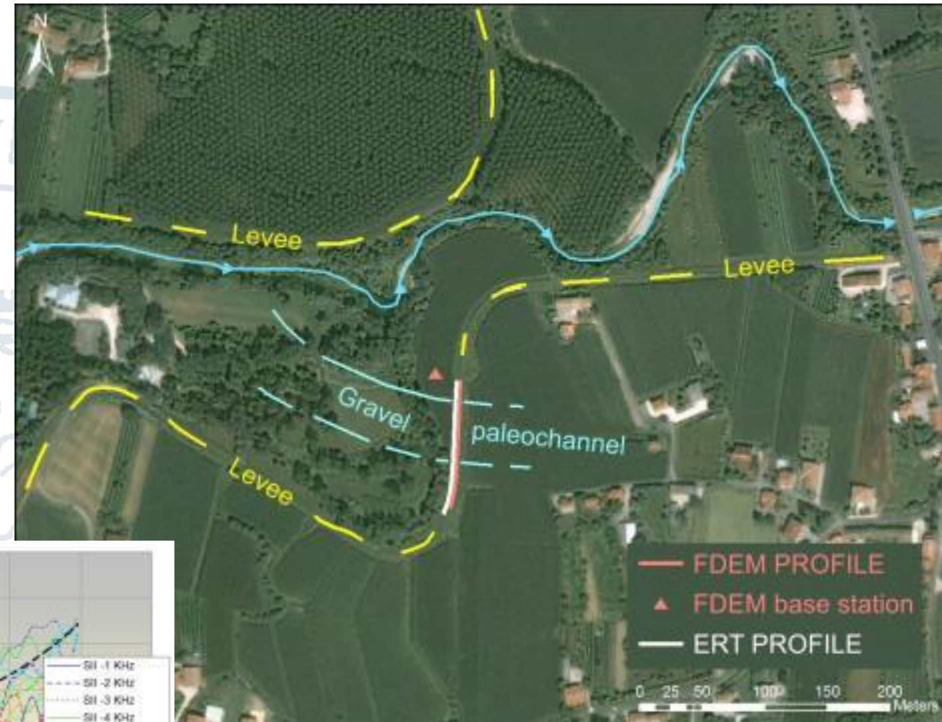
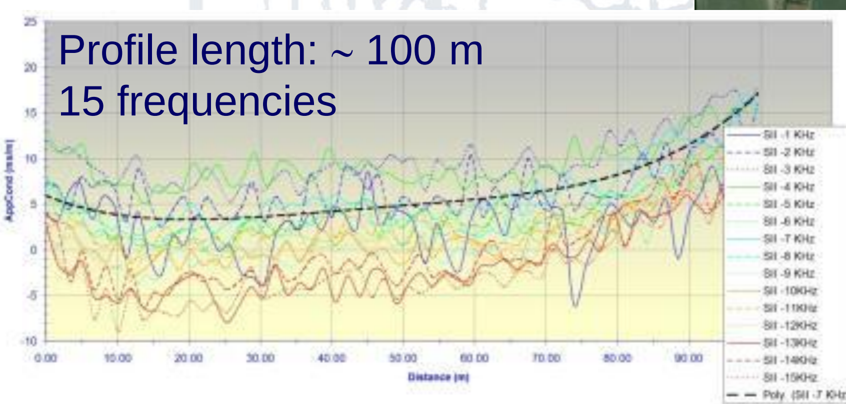
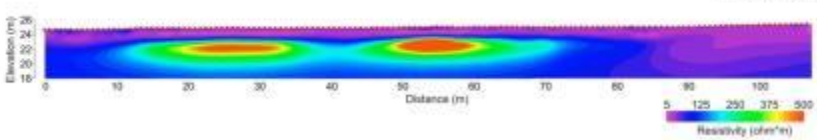
Data analysis and validation - multifrequency FDEM

<u>MULTIFREQUENCY FDEM</u>
(15 frequencies in the interval 1-15 KHz)

Was tested on a levee built over a well-known gravel paleochannel.







The FDEM response showed a clear lowering of the apparent conductivity in all the channels.

15 mS/m change in the 7KHz channel.

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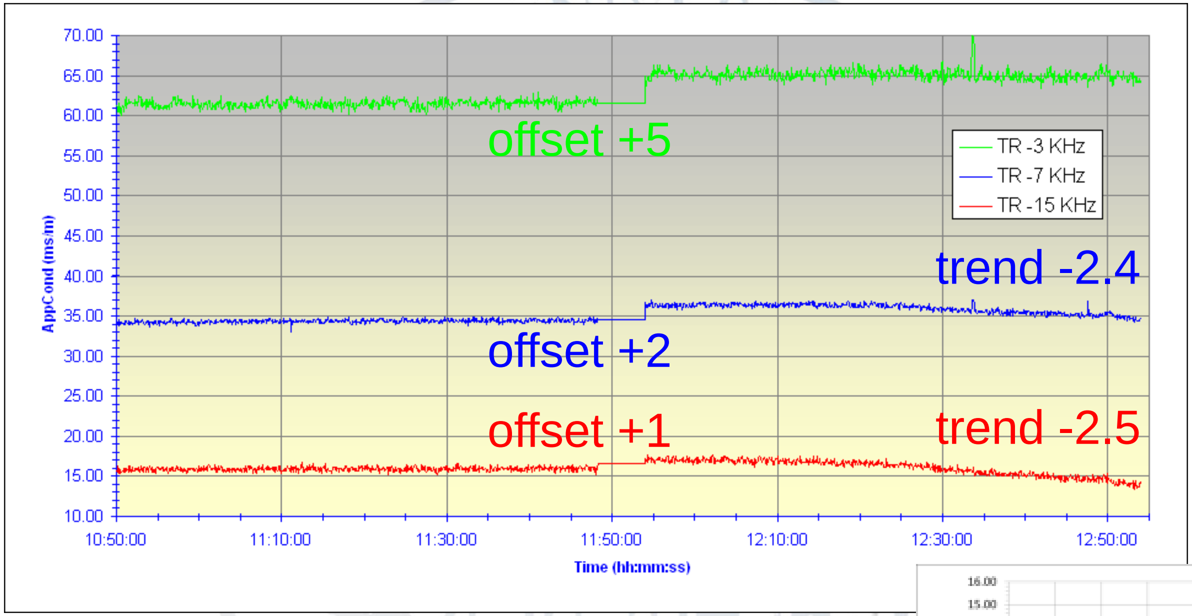
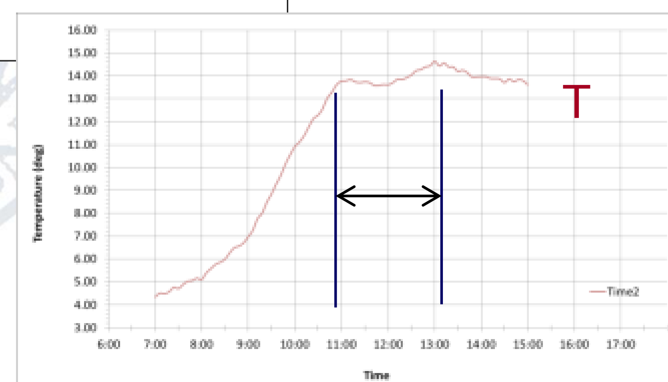
Data analysis and validation - multifrequency FDEM

MULTIFREQUENCY BASE STATION (outside the gravel body)
(3 frequencies: 3 KHz, 7 KHz and 14 KHz)



Approximately
2 hours of
observations

$\Delta T \sim 1$ degree



Offsets and trends were observed in the tested frequencies: ISSUE 1

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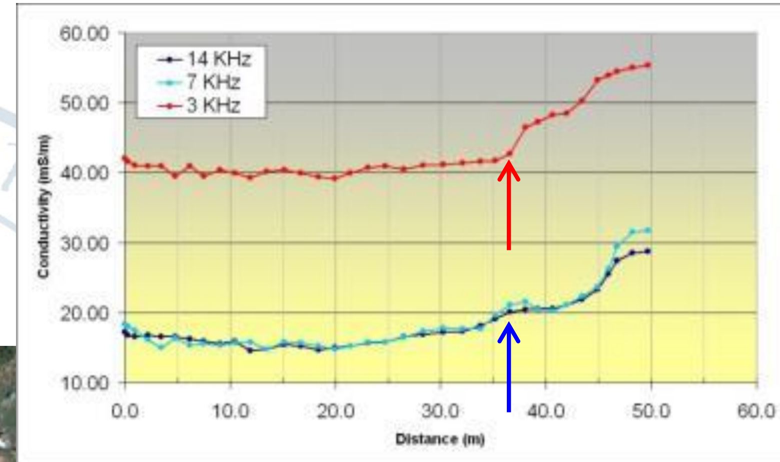
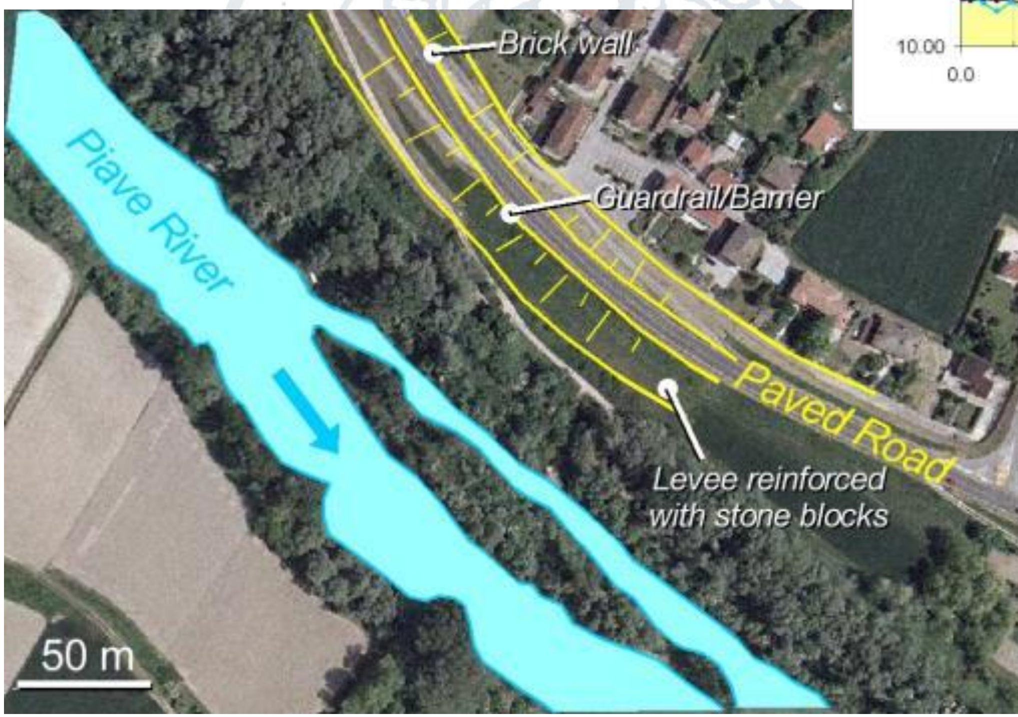
Data analysis and validation - multifrequency FDEM

A second issue regards the presence of secondary manmade structures on the earthen levee: ISSUE2.





Small walls or traffic barriers bounding the roads located on the top of the levees affect the EM measurements.

Stone blocks deployed to protect the base of the levee from erosion also affect the EM measurements.

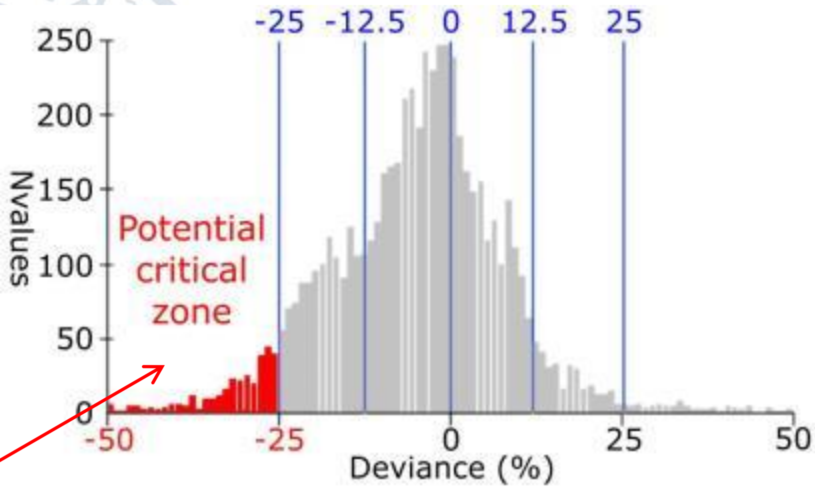
Data analysis and validation - multifrequency FDEM

Possible workarounds for ISSUE1 and ISSUE2.

1. Survey small enough segments to avoid drifting (10 minutes corresponding to about 1 km) during data collection.

The basic assumption is that the only change in the levee ensemble is due to its internal properties.

2. Survey “homogeneous” segments.

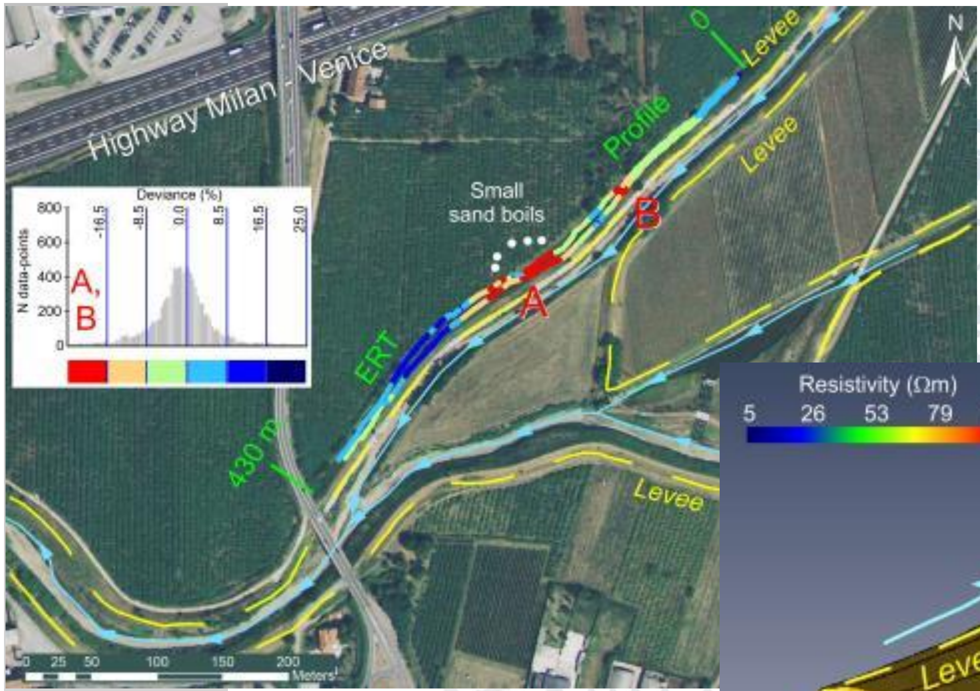


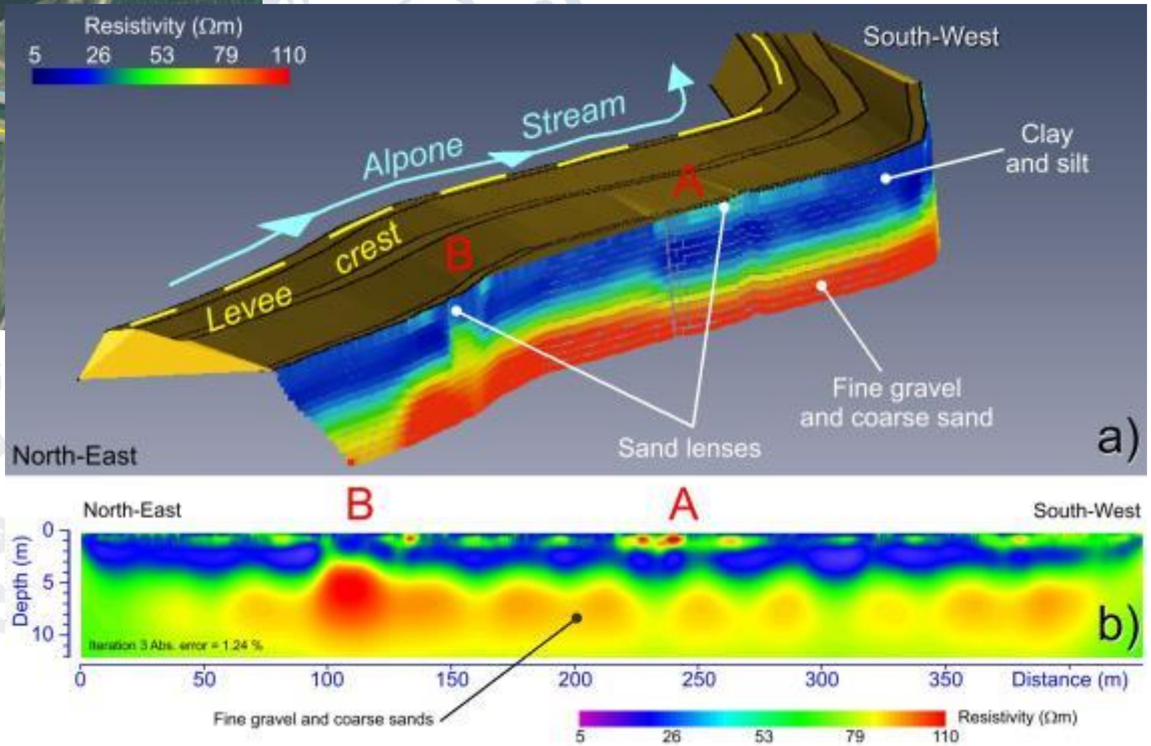
In the majority of the cases the deviation of the apparent conductivity shows a **normal** distribution

Each “homogeneous” levee segment was then processed separately and the anomalies (high permeability sand bodies or cavities), were identified as **large negative deviation** from a mean value typical of that levee segment.

Data analysis and validation - multifrequency FDEM

Case I





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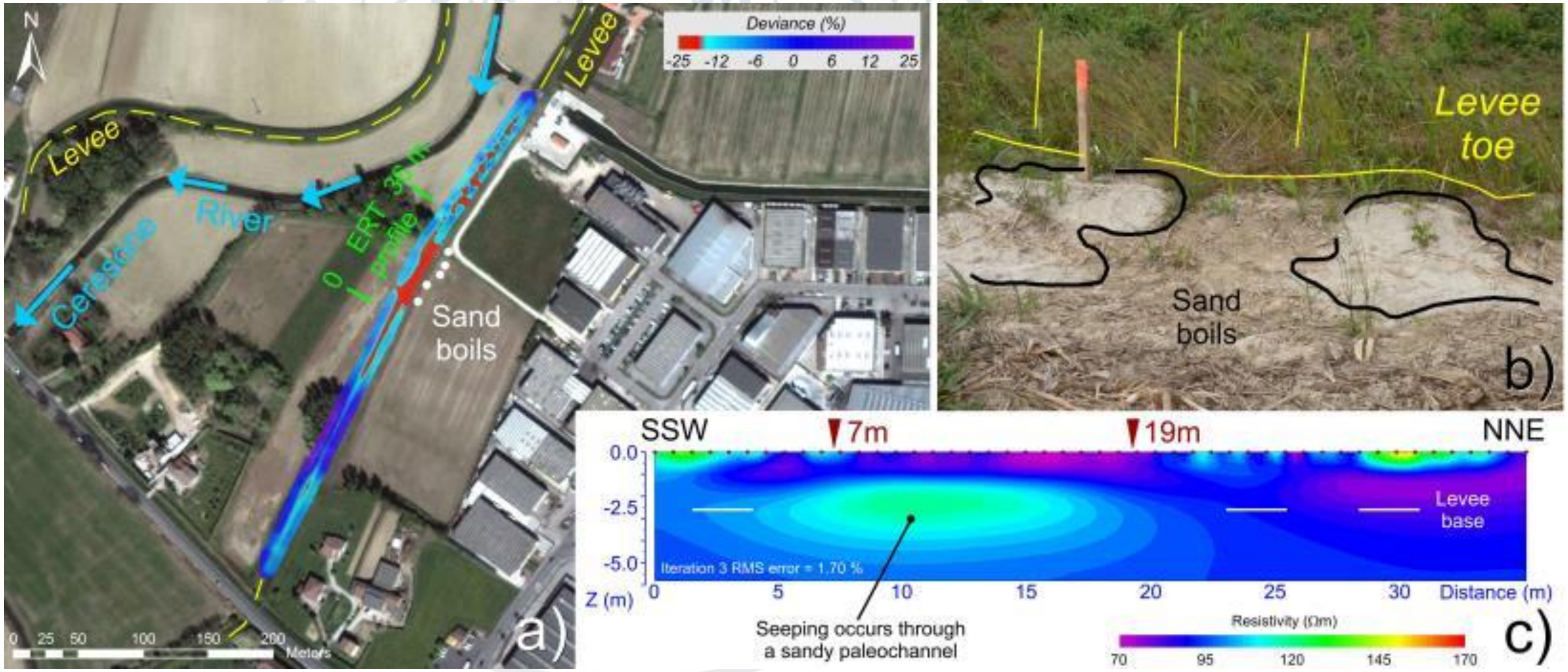
Data analysis and validation - multifrequency FDEM

Case II



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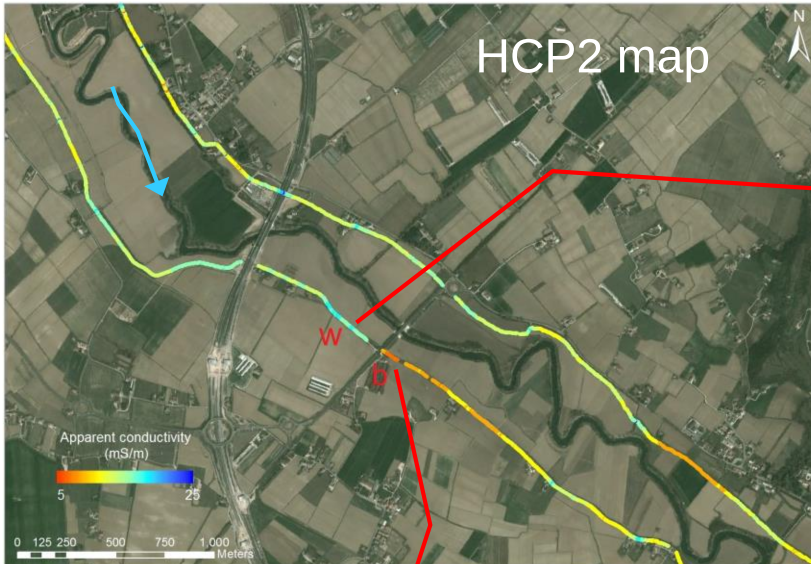
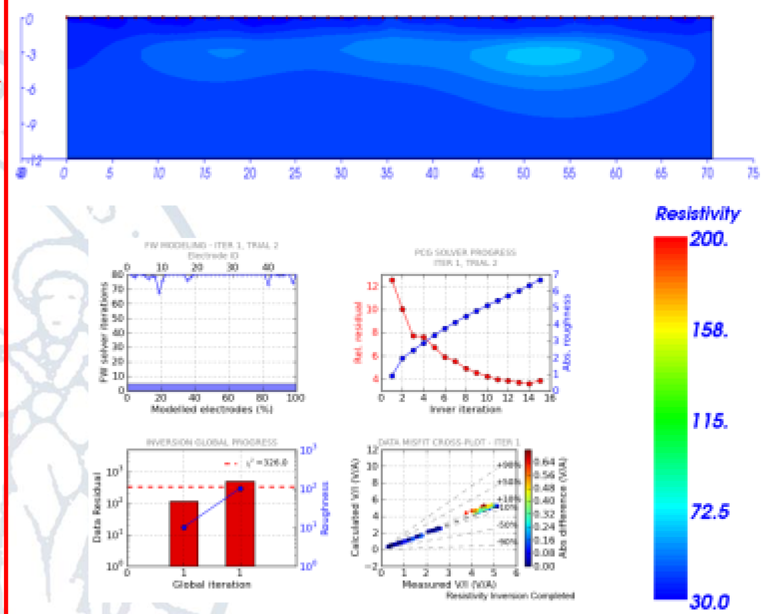
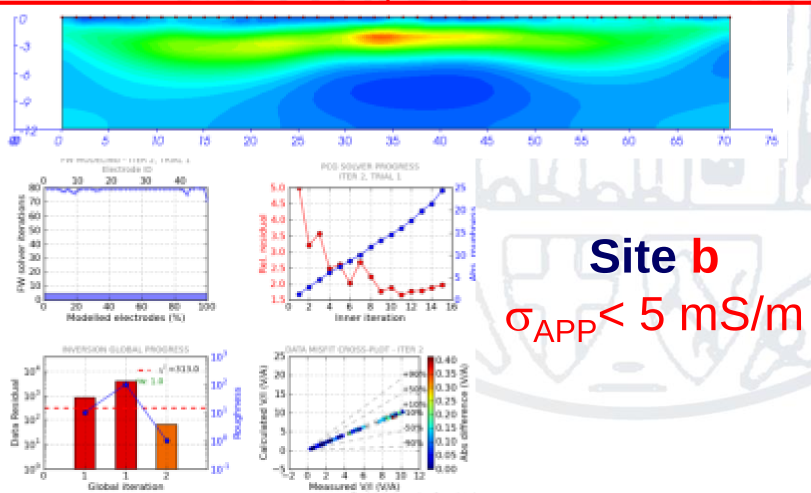
Data analysis and validation - multi-array FDEM



Site w (reference)





Site b

$\sigma_{APP} < 5$ mS/m

ERT imaging confirmed both the negative anomaly in **site b** and the absence of anomalies in the reference **site w**.

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Tsuh Lees Walde

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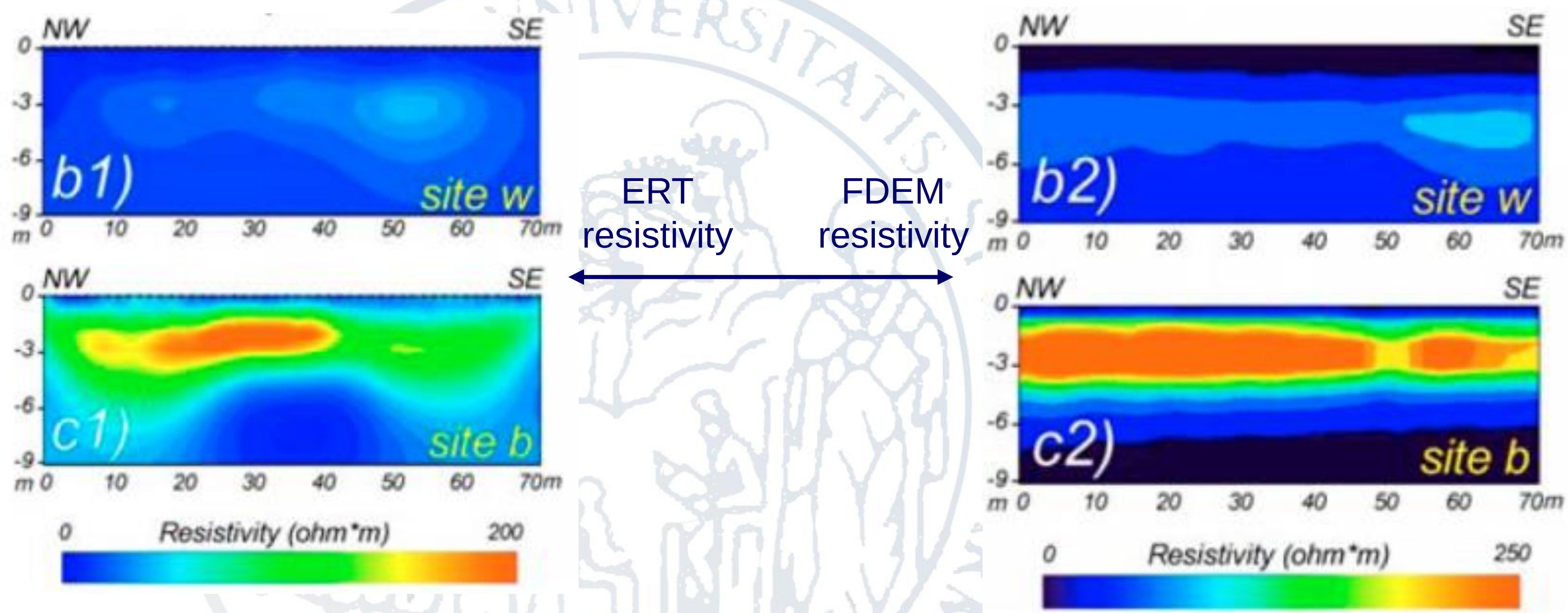
Data analysis and validation - multi-array FDEM

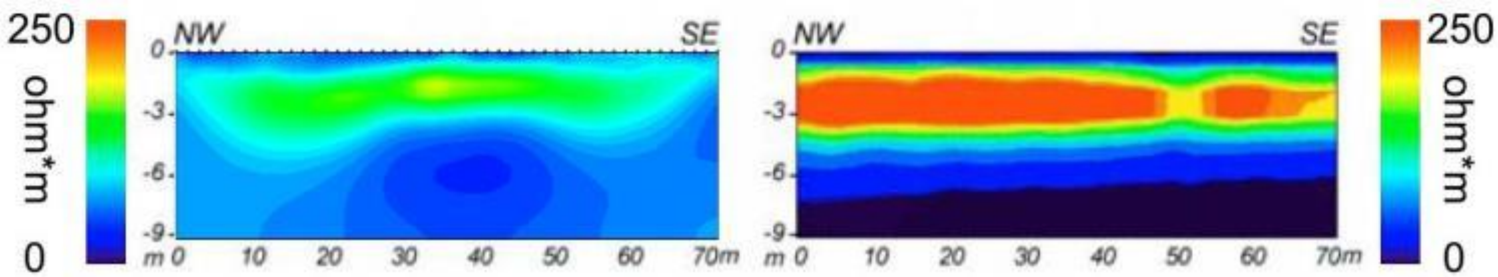
The FDEM data were also inverted and compared to the ERT profiles



Inversion was carried out with a smooth quasi-2D algorithm (*Monteiro Santos and El-Kaliouby, 2011*) using an homogeneous initial model of 30 mS/m and allowing for a maximum of 10 iterations. Comparison exhibits a good similarity although the values in the FDEM inversion are slightly larger (*Francese and Monteiro Santos, 2014*).

Data analysis and validation - multi-array FDEM

At site b the difference of 20-25 % in the absolute resistivity is not an issue as it does not affect interpretation. In other sites such a difference could be significant as silt and sandy silt layers could be interpreted as pervious sands.



A better convergence has been obtained lowering the number of iterations to 8 and using a three layer initial model.

At site w, in a fairly conductive environment, the FDEM and the resistivity inversions are almost identical.

Data analysis and validation – multichannel GPR

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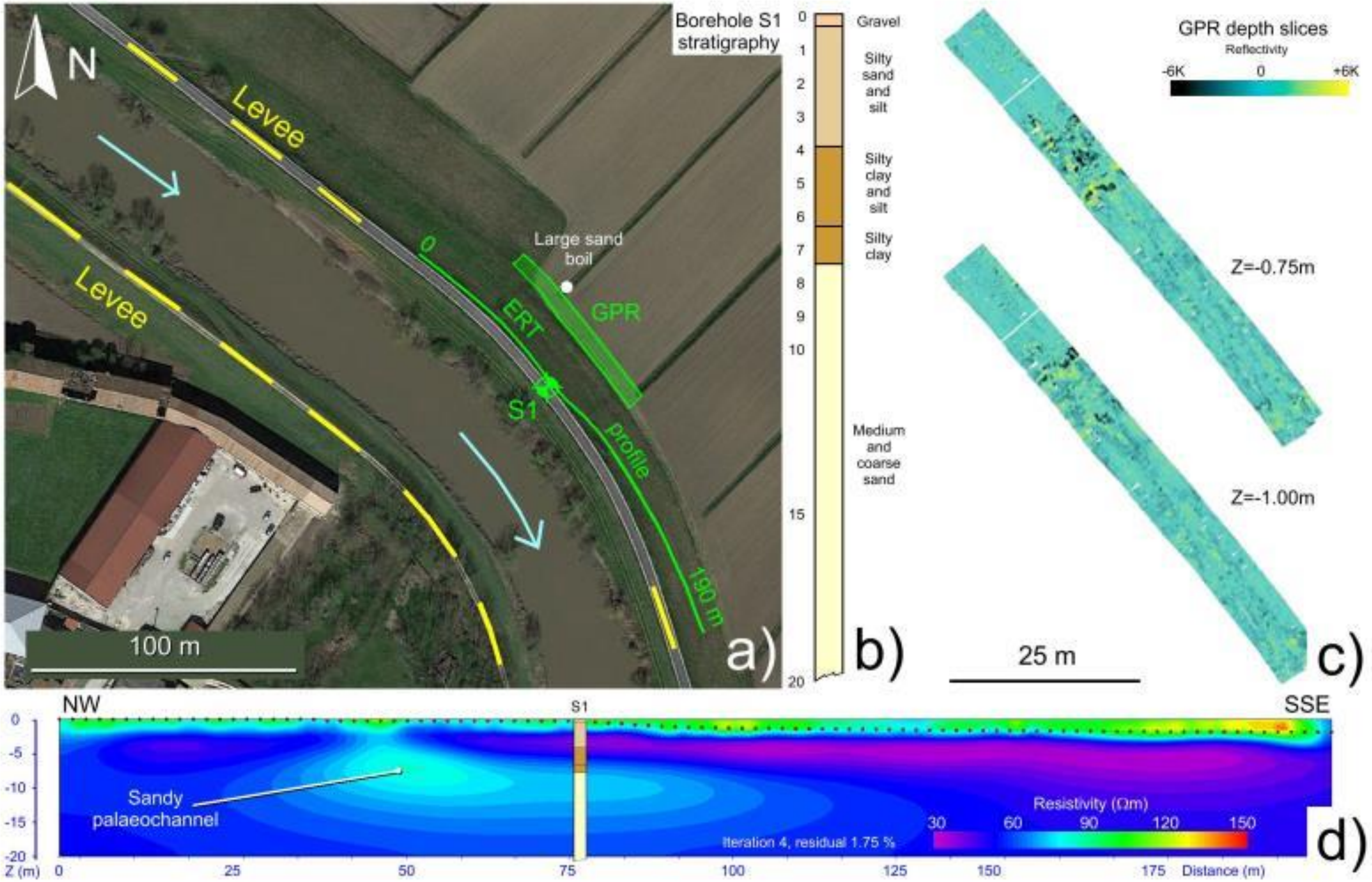

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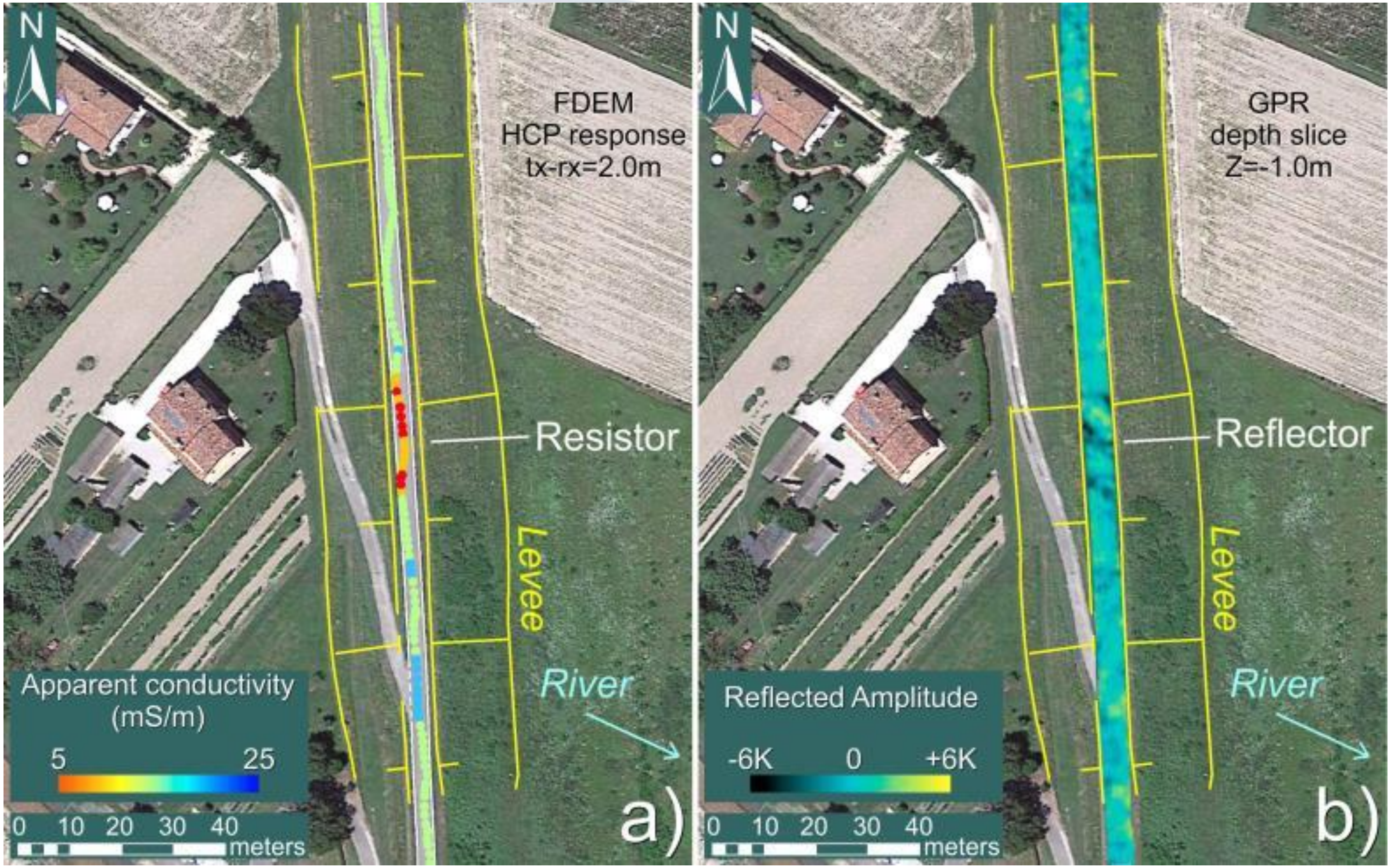
Data analysis and validation – multichannel GPR

The reflectivity map calculated at an approximate depth of 1 m below the levee crest showed a series on linear reflectors.



MULTI-CHANNEL GPR: (15 antennas - 200 MHz)

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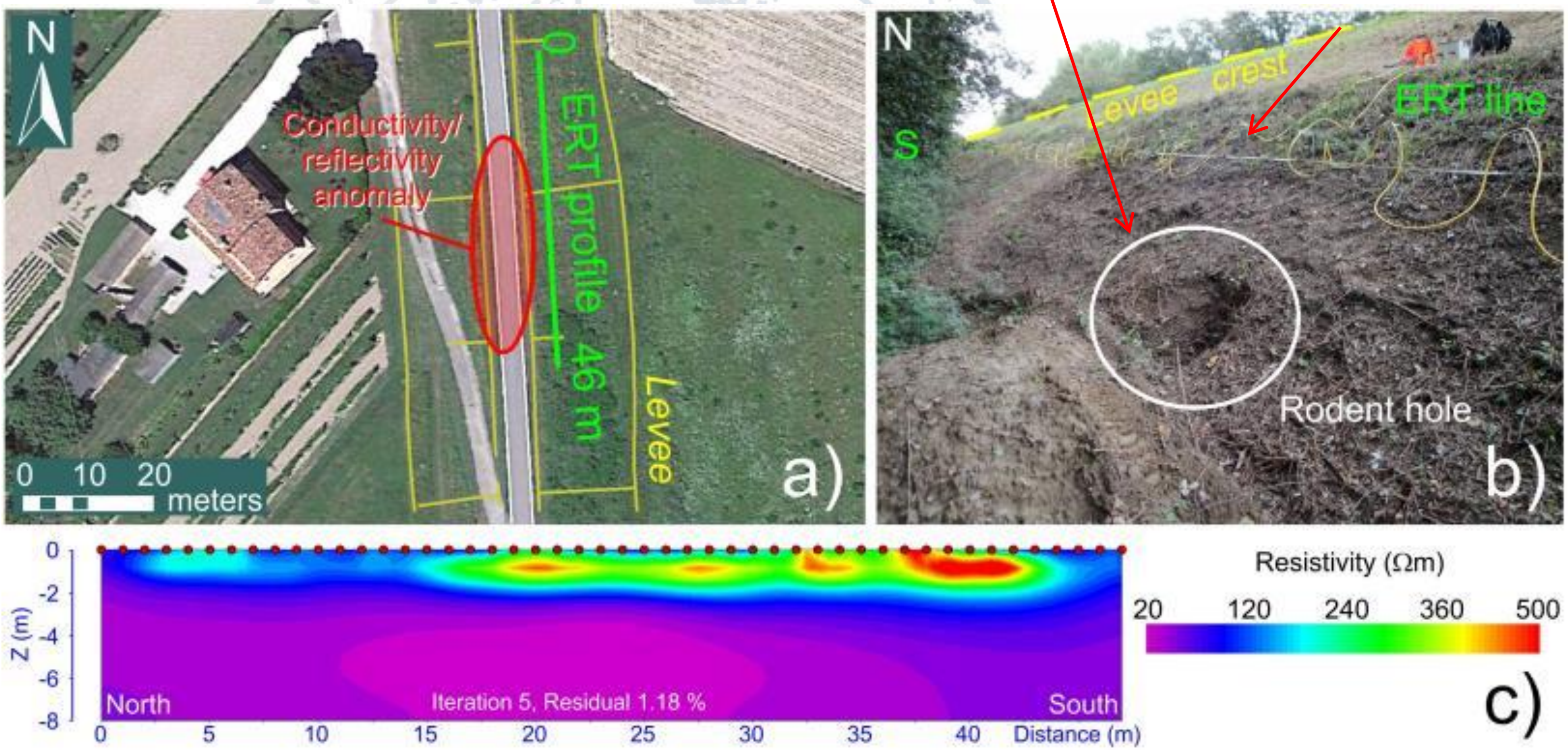
Data analysis and validation – multi-channel GPR

These reflectors were caused by cavities as confirmed by visual inspection and ERT profiling.



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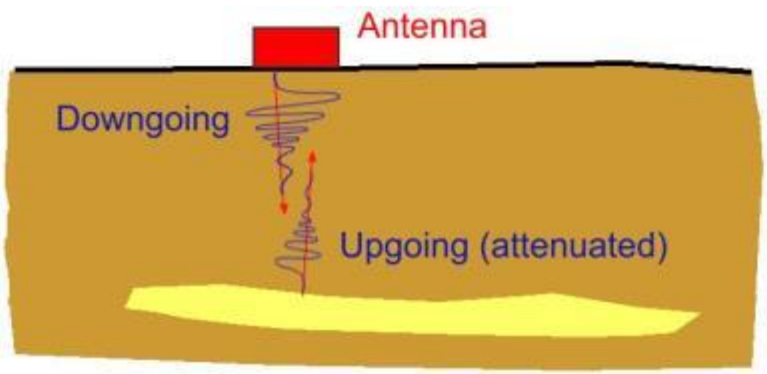
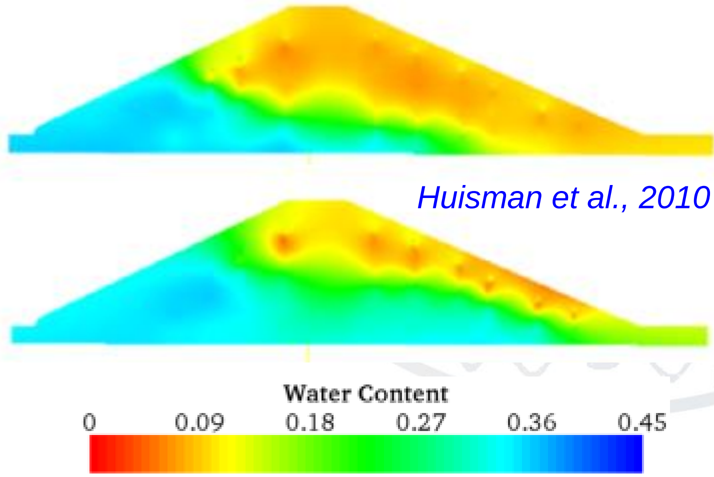
Data analysis and validation - residual drawbacks

The system is then validated although there are still some drawbacks ...

A. As known the GPR signal has a low penetration in a conductive environment (silt and clay). On the other hand GPR is the only geophysical technique capable of delivering enough resolving power to detect the animal cavities in the top portion of the levee.





B. Changes in the water content of the levee itself could significantly affect the EM measurements and the overall values could be of the same order of magnitude of the expected anomalies.

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Possible solutions for issues A and B

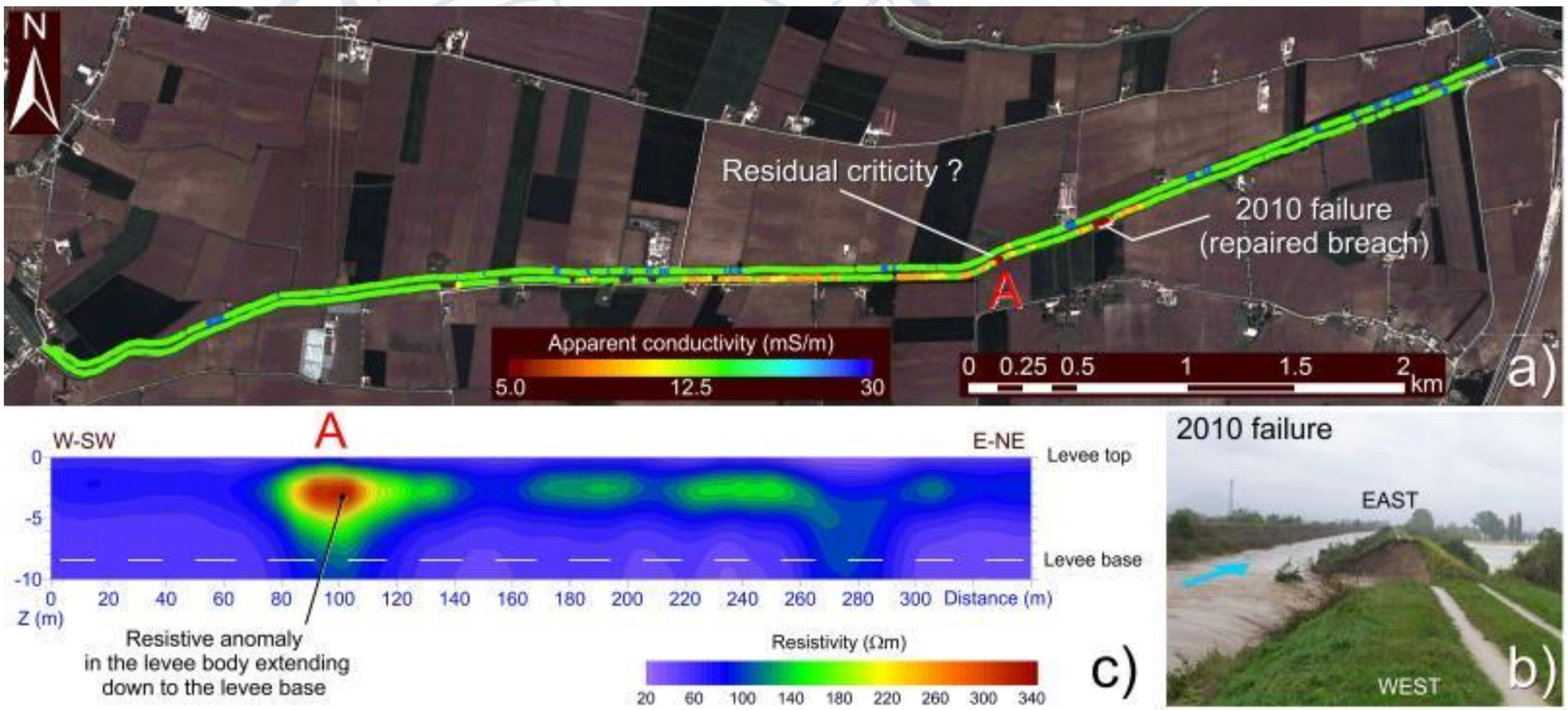
A. It’s mostly a physical limitation as in many cases the resistivity of the levee body is lower than 50 ohm*m. In order to increase the depth of penetration of the GPR signal data acquisition should be carried out after a dry period (preferably during the summer).

B. The opposite is true for the FDEM data acquisition. In order to minimise the effect of varying water content within the levee body FDEM data should be collected after few days of rain. In this conditions the levee could be considered wet.

It’s then better to carry out a double survey.

Results and discussion

Case study I



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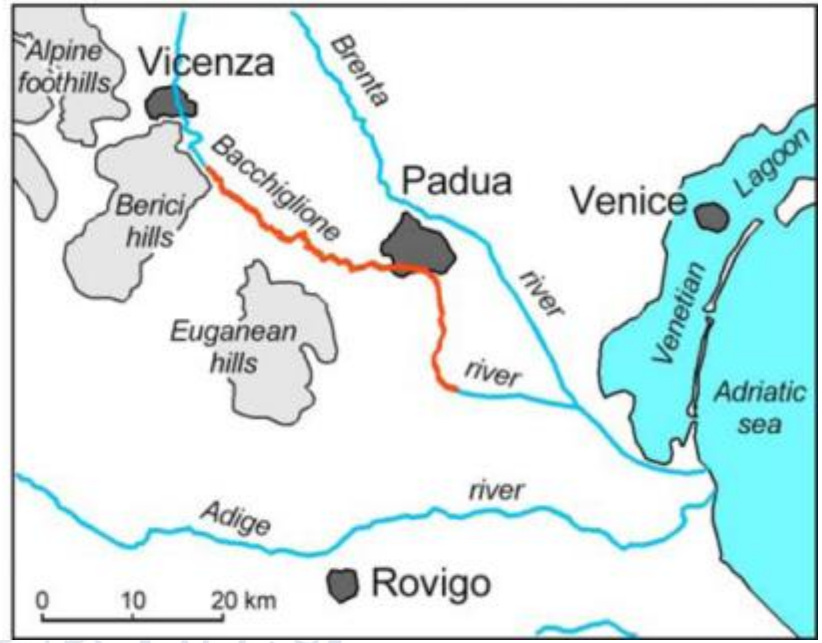
Results and discussion



Bacchiglione river:
90 x 2 km
of dual survey

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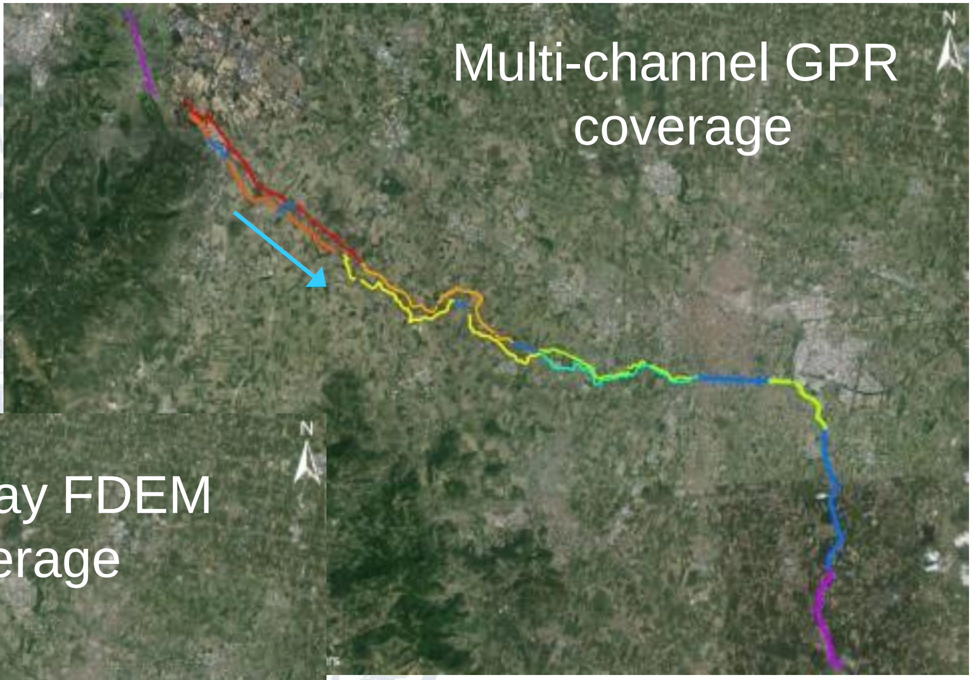
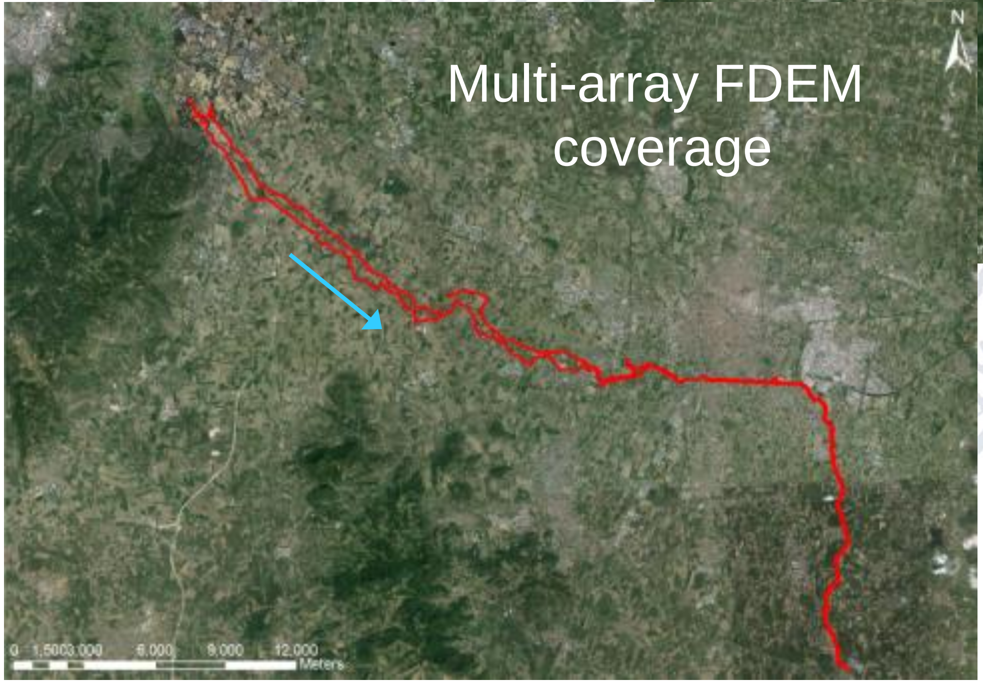
Results from a large scale project

Survey figures:

~ 500K FDEM data points
~ 18,000K GPR traces

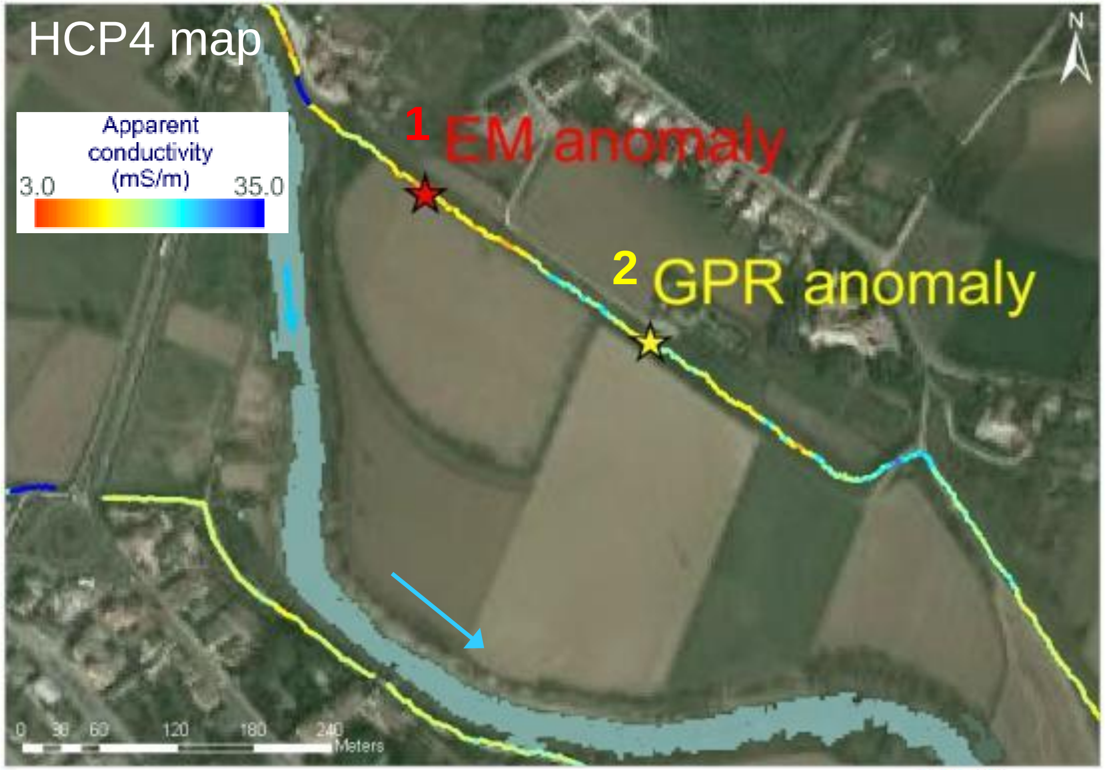
~ 1 week for each dataset
working crew of two people





GPR measurements were carried out during the summer 2013 while FDEM data were collected during late autumn-early winter of the same year.

Results from a large scale project

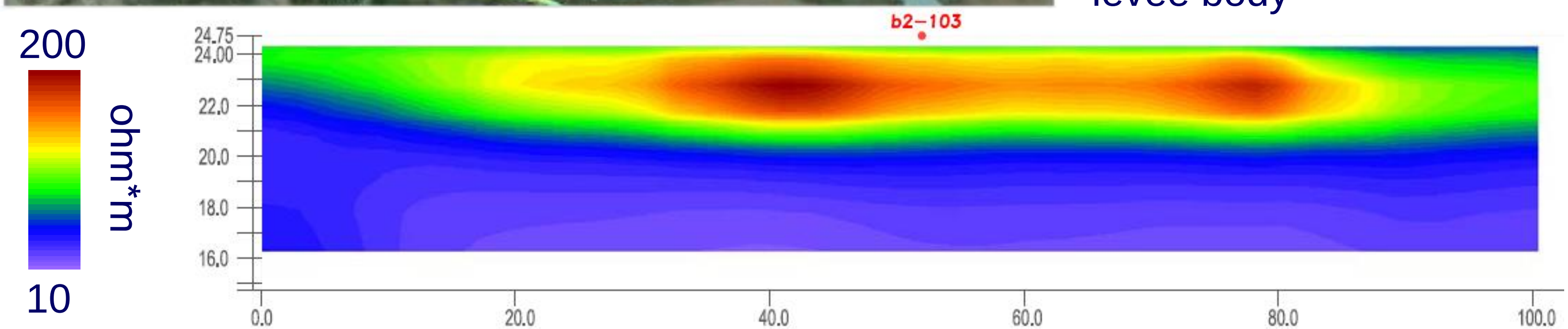


1. FDEM anomaly

σ_{APP} < 5 mS/m

The anomaly was visible both in the HCP2 and HCP4 maps

FDEM inversion shows a resistive layer (ρ > 200 ohm*m) in the levee body



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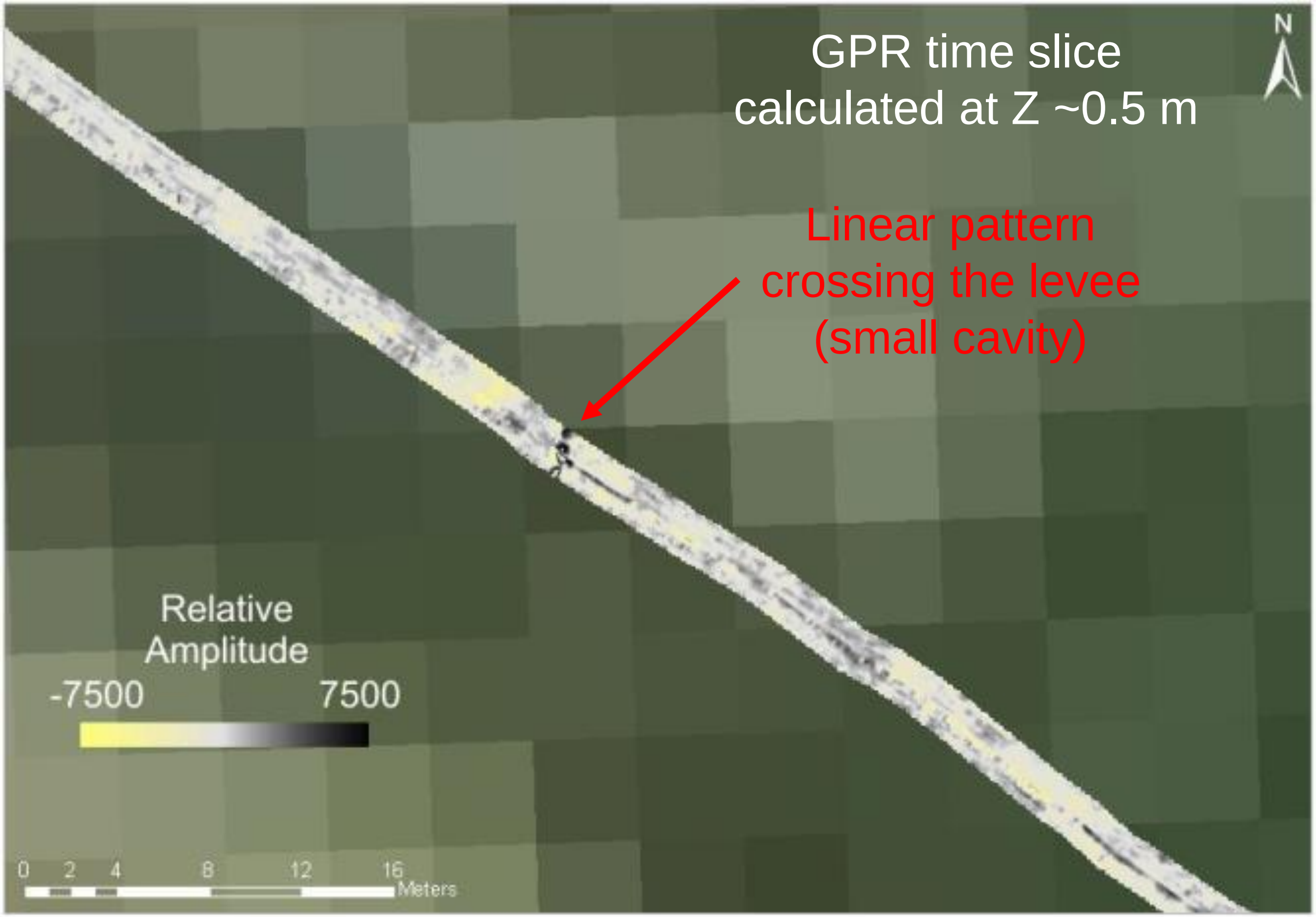
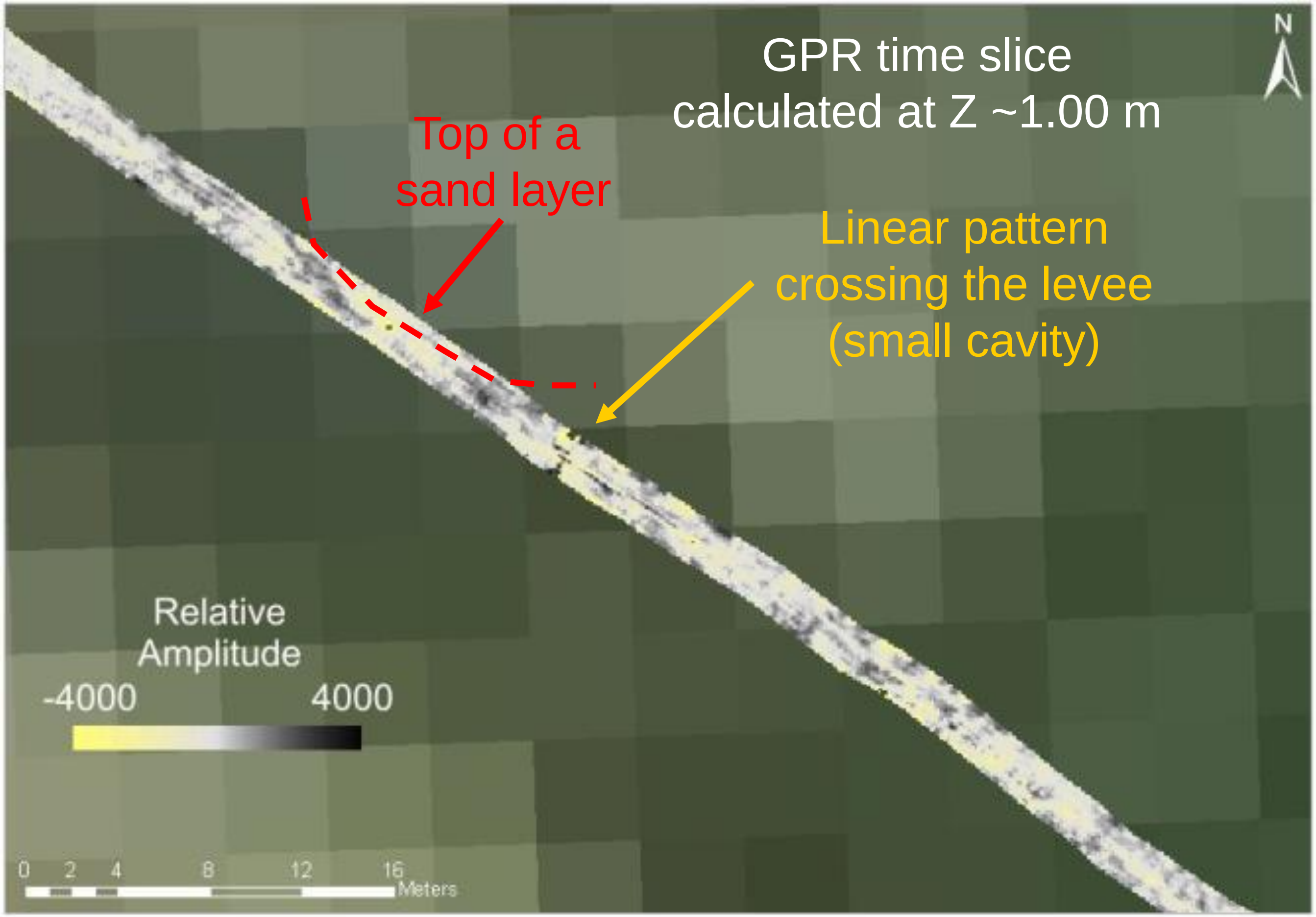
Results from a large scale project

2. GPR anomaly:



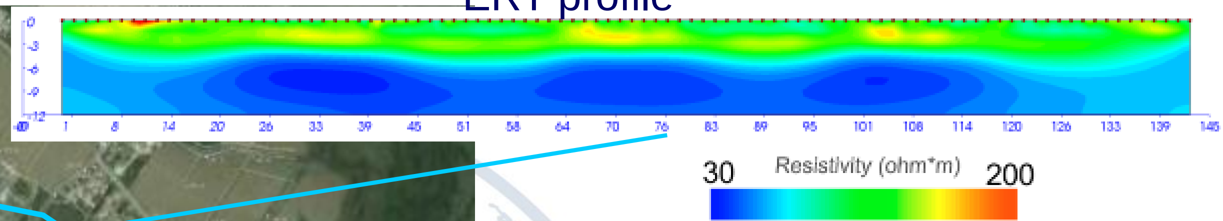
Results from a large scale project

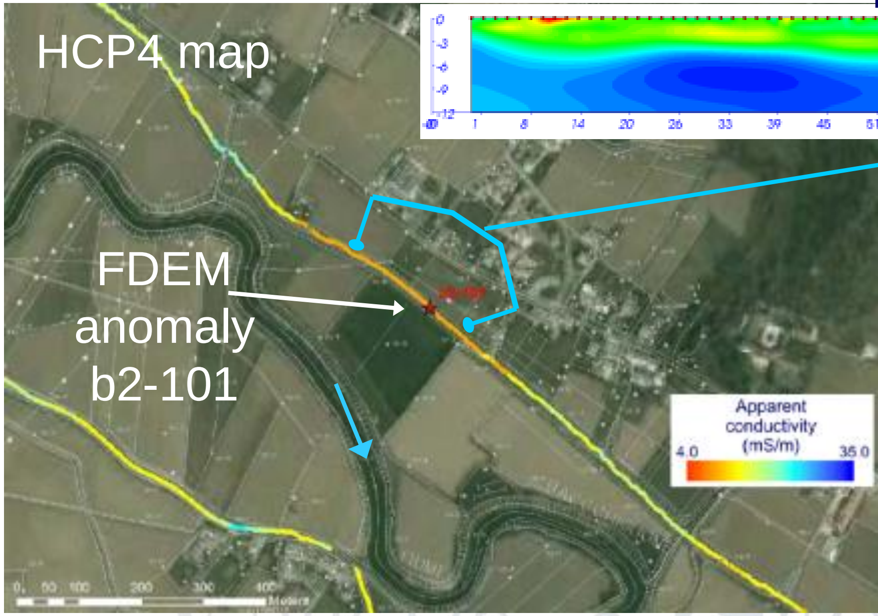
2. GPR anomaly:

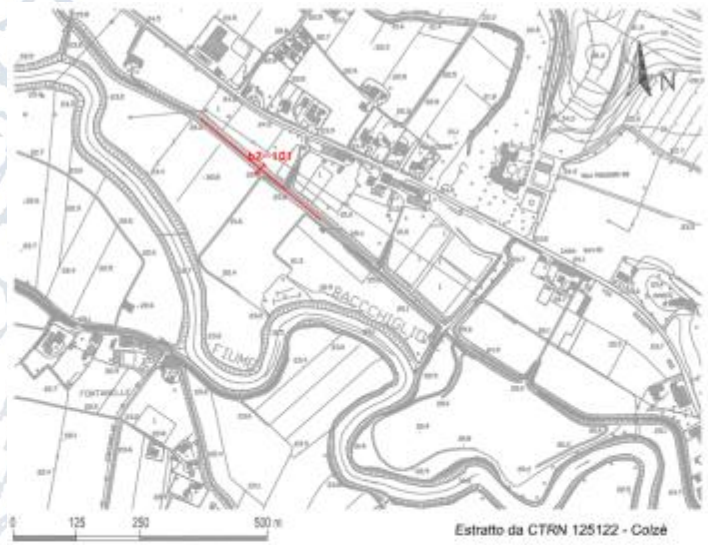


Results from a large scale project

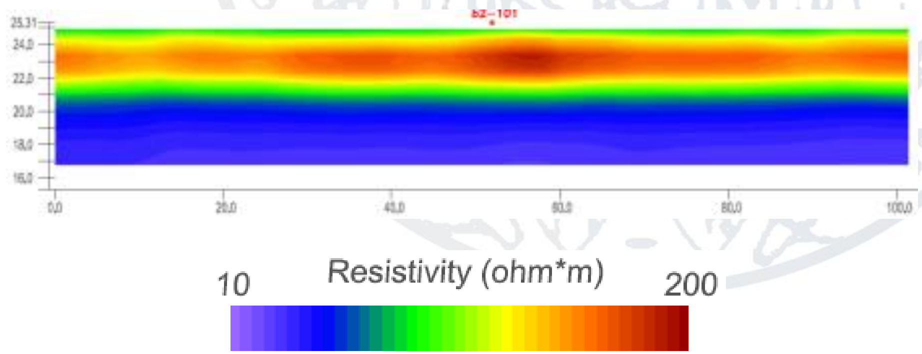
ERT profile

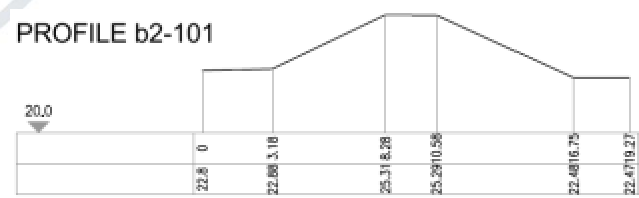




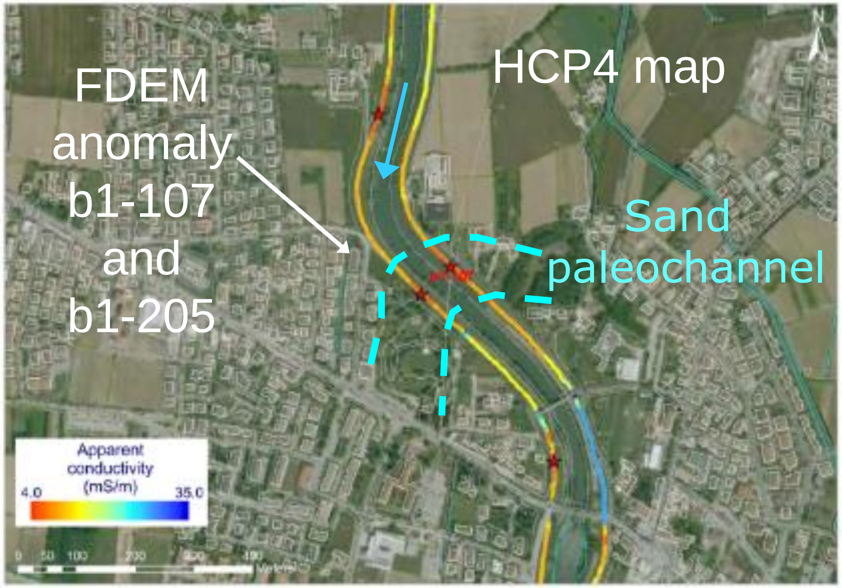


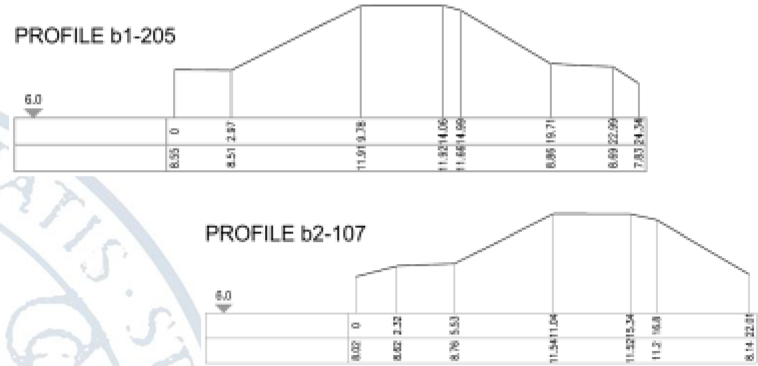
FDEM inversion



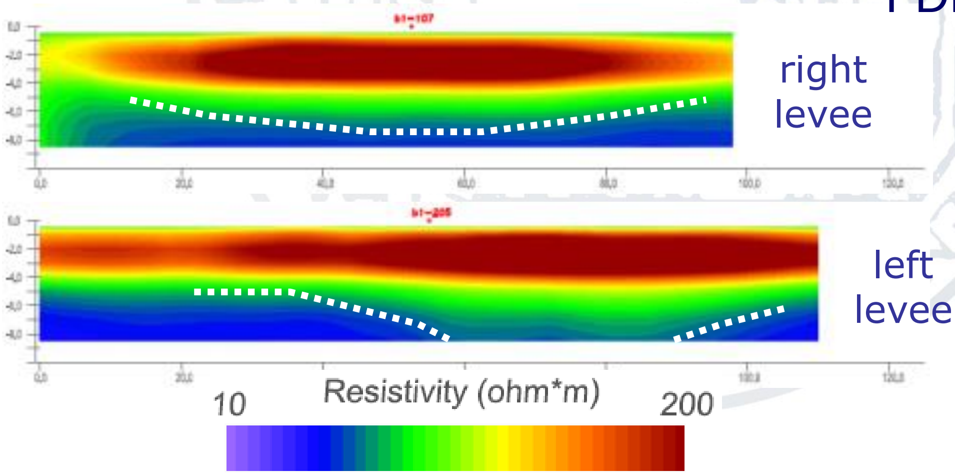


Results from a large scale project





FDEM inversion



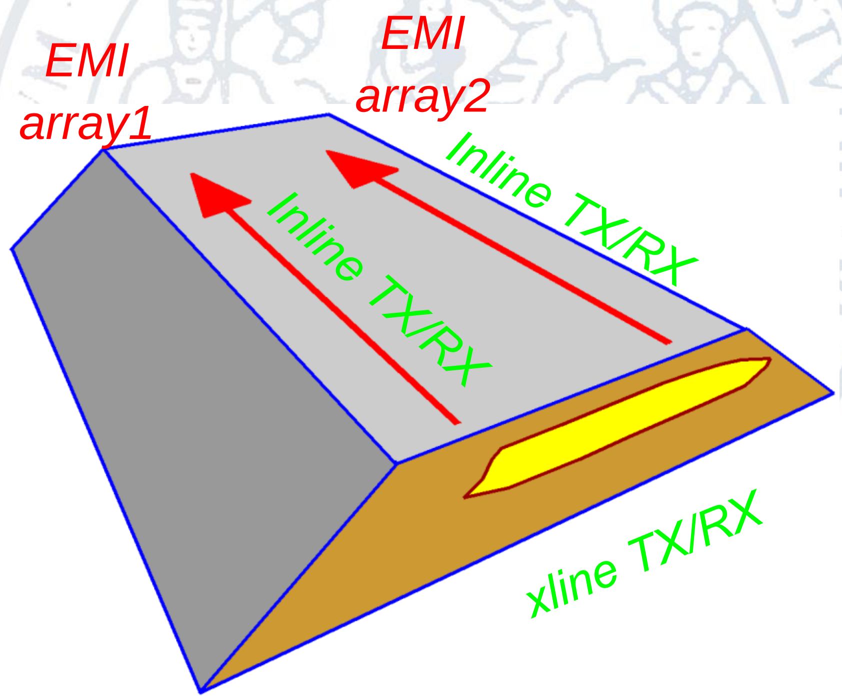
In this area during floods was frequently observed water piping underneath the levee base.

Roberto Francese et al,, 2019

Current improvements

Among the limitations of this approach there is the impossibility of mapping the position of the pervious (sand/cavity) body with respect to the levee axes (in the FDEM measurements).

Laying the EMI coils in two rows should overcome this limitation.



Furthermore using this configuration it's possible to collect inline and xline data increasing the resolution in the top portion of the levee.

Conclusions (1)

- A fast and efficient geophysical method to scan earthen levees has been experimented and validated;

- The method is based on a dual survey comprised of <u>multi-channel GPR</u> and <u>multi-array fixed frequency FDEM</u>;

- Inversion of the FDEM data led to resistivity images fully comparable to ERT imaging. This procedure still requires some tuning of the processing parameters but its already in the range of the achievements and this results in no need of validating the FDEM anomalies with time-consuming ERT profiles;

Conclusions (2)

- Single pass surveying would be a major breakthrough in the cost-effectiveness of the method. This is probably feasible increasing the number of the EM sensors to improve the resolution in the uppermost layers. In this last case a quasi-3D EM inversion of the data would be required;

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