« Aquifères de socle : le point sur les concepts et les applications opérationnelles »
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MULTI-SCALE APPROACH IN HYDRAULIC CHARACTERIZATION OF HARD ROCK AQUIFERS: A CASE OF STUDY FROM PALEOZOIC METARENITES OF SARDINIA (ITALY)

APPROCHE À DIFFÉRENTES ÉCHELLES POUR LA CARACTÉRISATION HYDRODYNAMIQUE D'UN AQUIFÈRE DE SOCLE: UN CAS D'ÉTUDE DE MÉTAARÉNITES PALÉOZOÏQUES DE SARDAIGNE (ITALIE)

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Hard-rock aquifers are recognized to be highly heterogeneous. This implies that the bedrock transmissivity can vary over many orders of magnitude. Therefore, well yields are highly variable.

In Italy:

hard rocks outcrop over large areas in the Alps, Calabria and Sardinia,

hydrogeological properties of plutonic and metamorphic rocks are not well known,

groundwater yields of these aquifers are lower than those in the more common carbonate and alluvial aquifers,

interest in hard-rock aquifers is thus generally scarce,

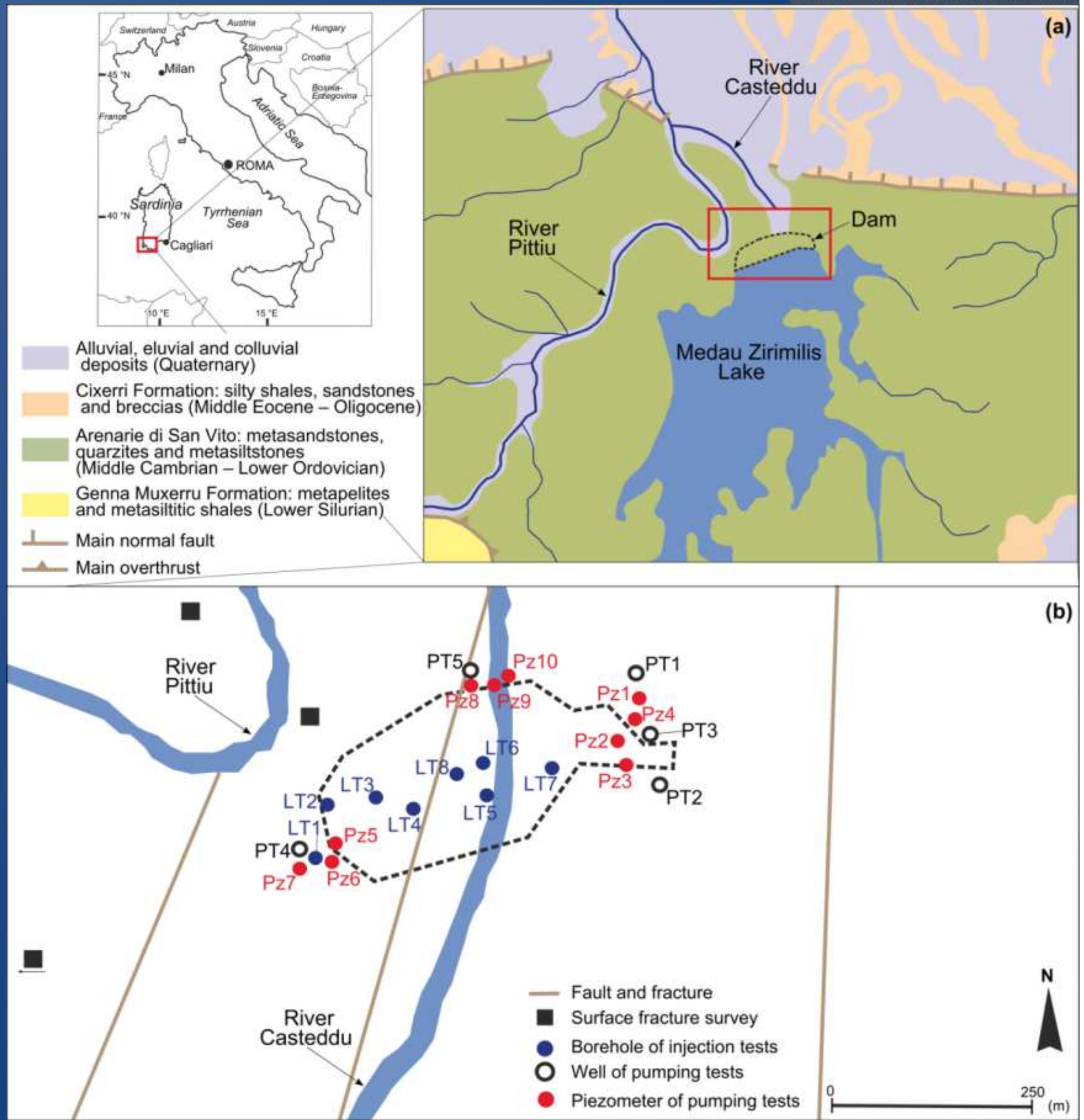
but the large extent of these rocks and the scarcity of water resources in Sardinia and Calabria justify a thorough analysis.

The case study: dam site in metamorphic rock in Sardinia

Paleozoic basement of an originally sedimentary succession.

Arenarie di San Vito Formation: several hundred meters thick of alternations between micaceous metasandstones, quartzites and metasiltstones.

Medau Zirimilis Dam: a 50-m-high rockfill dam completed with an upstream impervious face and with a grout curtain 10-50 m deep.

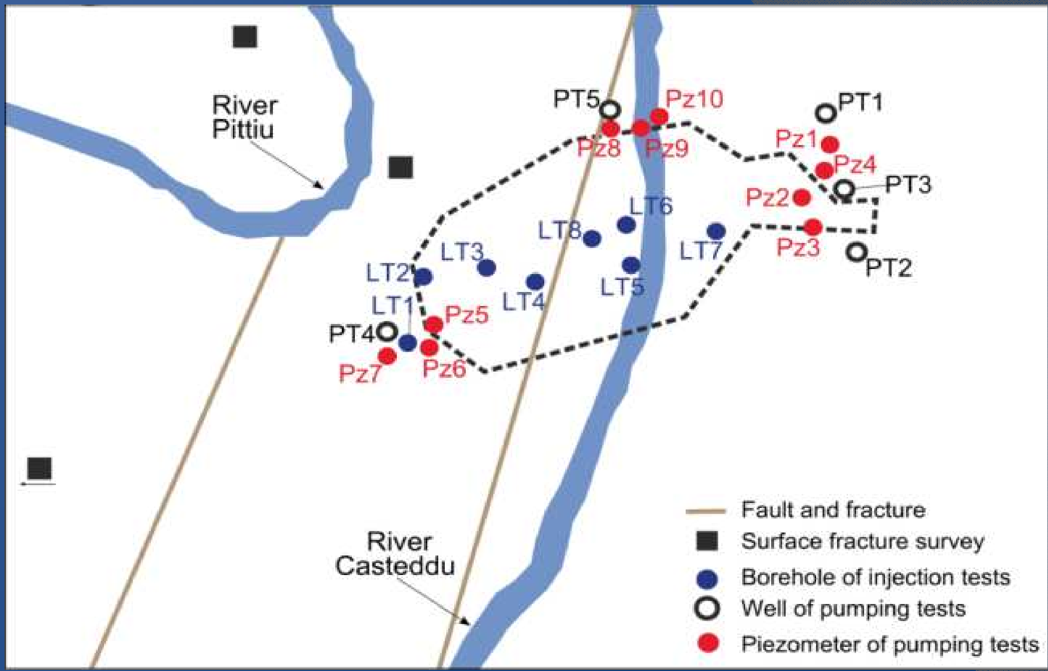


Previous investigations highlighted:

seepage through the rock foundation and laterally to the dam ,

the groundwater circulation involved the most fissured layers closest to the surface, on average the first 50 m up to a depth of 100 m in the faulted zones,

the most evident faulted zone has been found in the valley bottom.

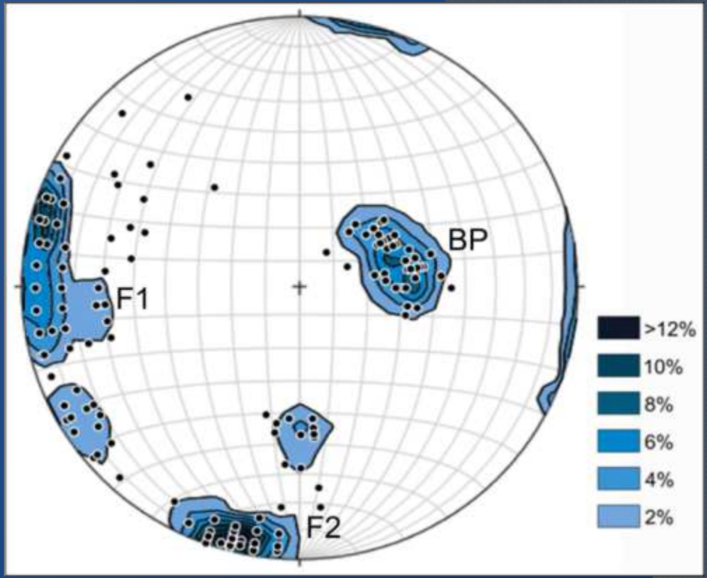


New investigations and revision of previous survey:

- *surface fracture survey*
- *injection tests*
- *pumping tests*

Surface fracture survey

Two discontinuity types were identified: bedding planes (BP) and sub-vertical straight joints (F1 and F2).



Characteristic	BP	F1	F2
Mean dip direction (°)	255.1	91.9	11.9
Mean dip angle (°)	29.2	78.1	75.8
Mean spacing (cm)	26.20	24.45	10.47
Mean aperture (mm)	0.12	0.15	0.15

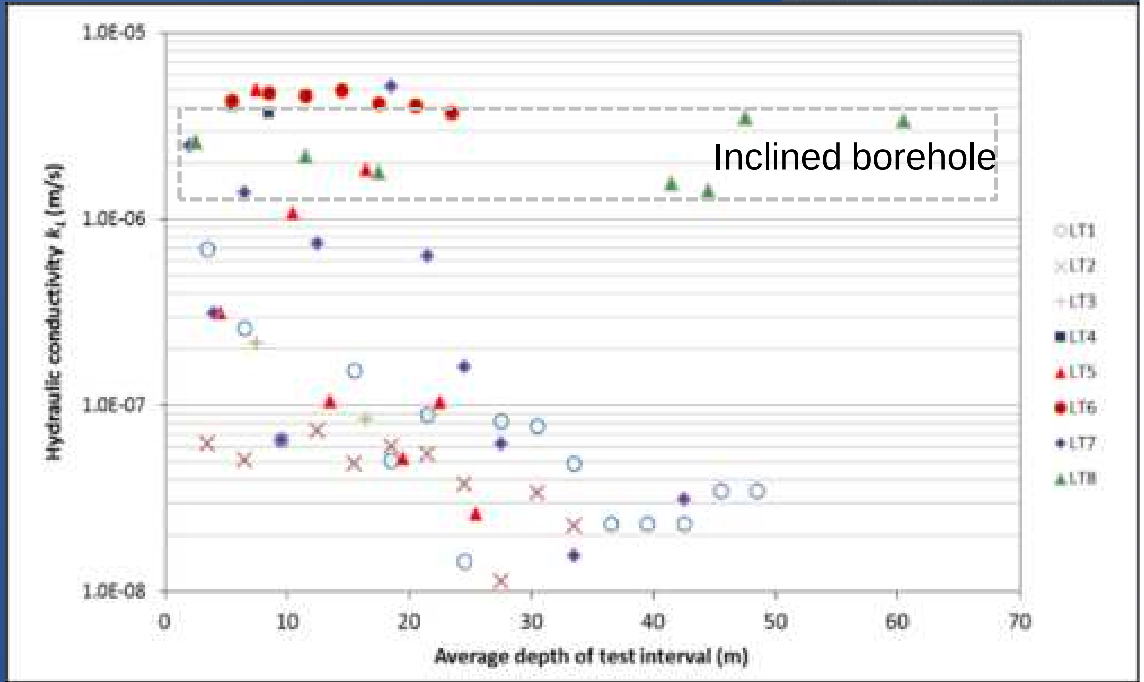
Set	k (m/s × 10^{-5})
BP	0.54
F1	1.13
F2	2.64

According to the cubic law hydraulic conductivity of each set was determined, and then values and orientation of the major, intermediate and minor components of the hydraulic conductivity of rock mass were determined.

Components	Value (m/s × 10^{-5})	Trend (°)	Plunge (°)
Minor	1.58	201	15
Intermediate	3.19	109	6
Major	3.84	359	74

Injection tests

76 Lugeon tests in 8 boreholes: maximum depth of 60 m; one of the boreholes was drilled with a dip angle of 60°.



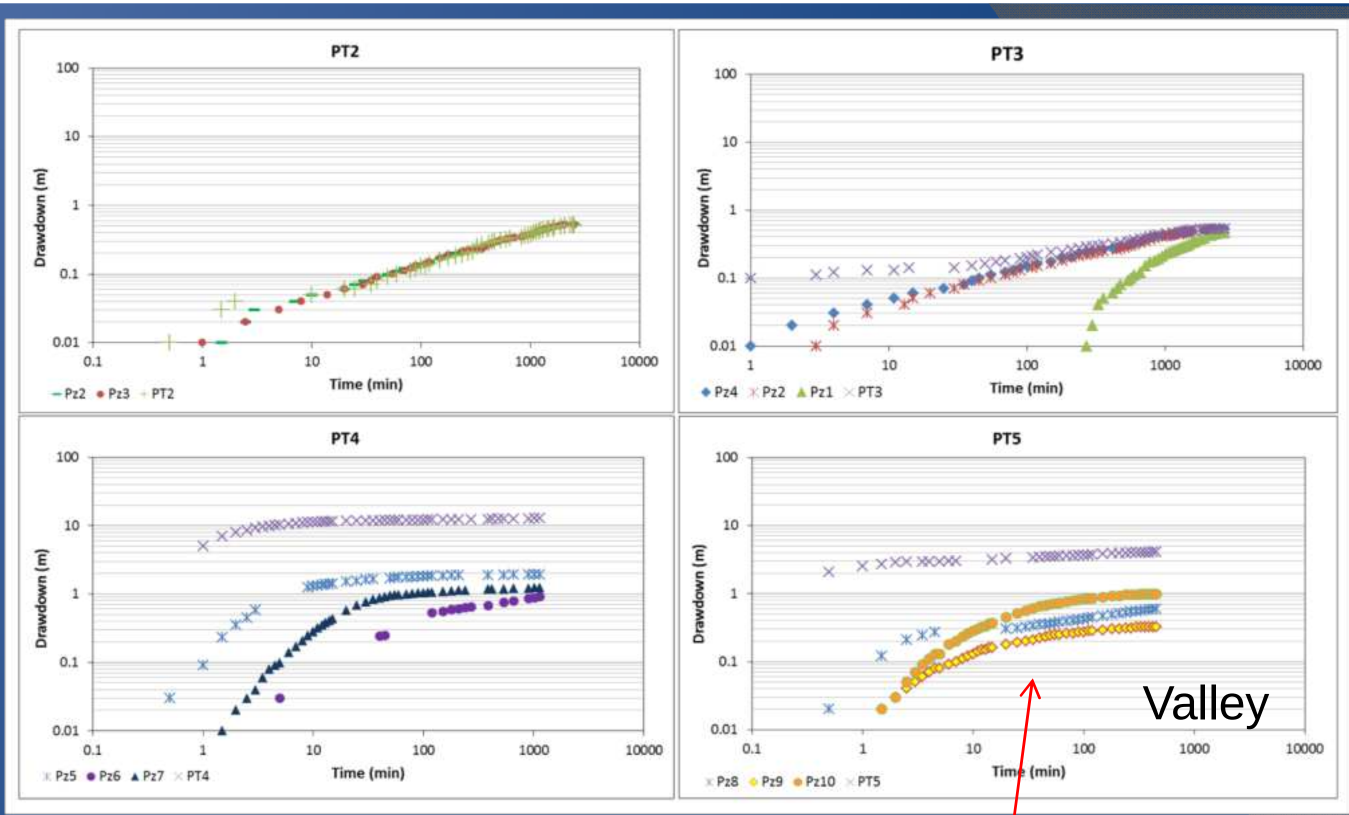
Hydraulic conductivity: 10^{-8} – 10^{-6} m/s

At depths greater than 25 m, there was a significant decrease in the hydraulic conductivity, with the exception of the inclined borehole.

Above a depth of 25 m, the boreholes that were located in the valley bottom, corresponding to a faulted zone, exhibited a higher hydraulic conductivity.

Pumping tests

5 wells
Depth: 73-100 m
Discharge: 2.1-3.5 L/s



Observation of drawdown in at least one piezometer nearby the tested well: simultaneous response to the pumping, and generally, a similar shape for the drawdown curve for the different observation wells.

$T = 2.3\times10^{-4} - 3.6\times10^{-3}\ m^2/s$
$S = 3.1\times10^{-5} - 2.6\times10^{-2}$
$K = 4.6\times10^{-6} - 4.1\times10^{-5}\ m/s$

Results

Surface fracture survey :

- the rock mass is characterized by a well-developed discontinuity network
- the discontinuity network gives rise to a slight anisotropy in the medium

Injection tests:

- the extreme heterogeneity of the rock mass (10^{-8}–10^{-6} m/s)
- the highest values of K were found for the inclined borehole, close to the fault zone
- K deacreses below a depth of 25 m

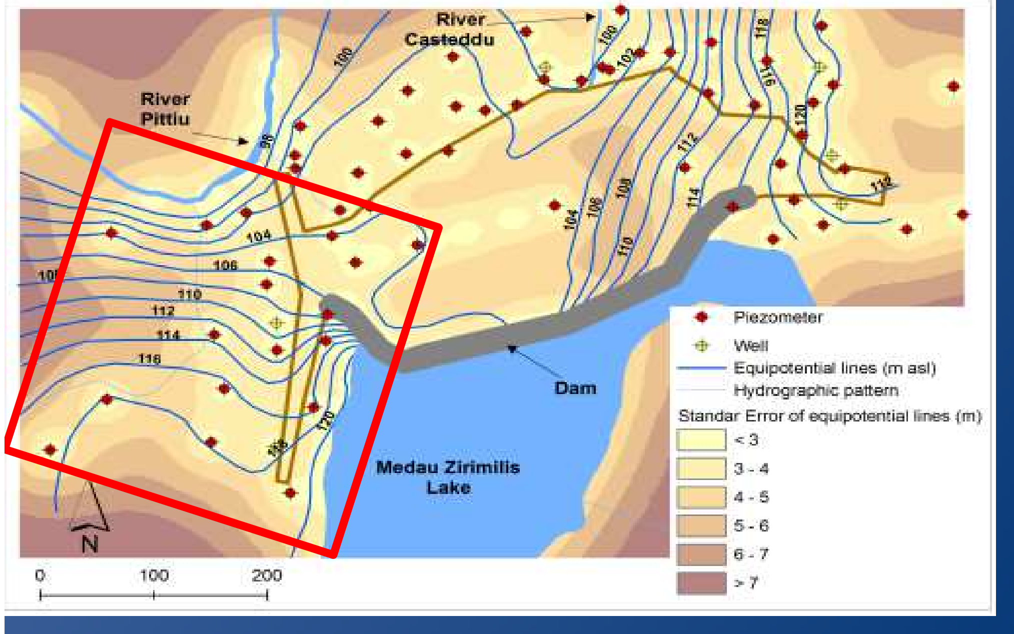
Pumping tests :

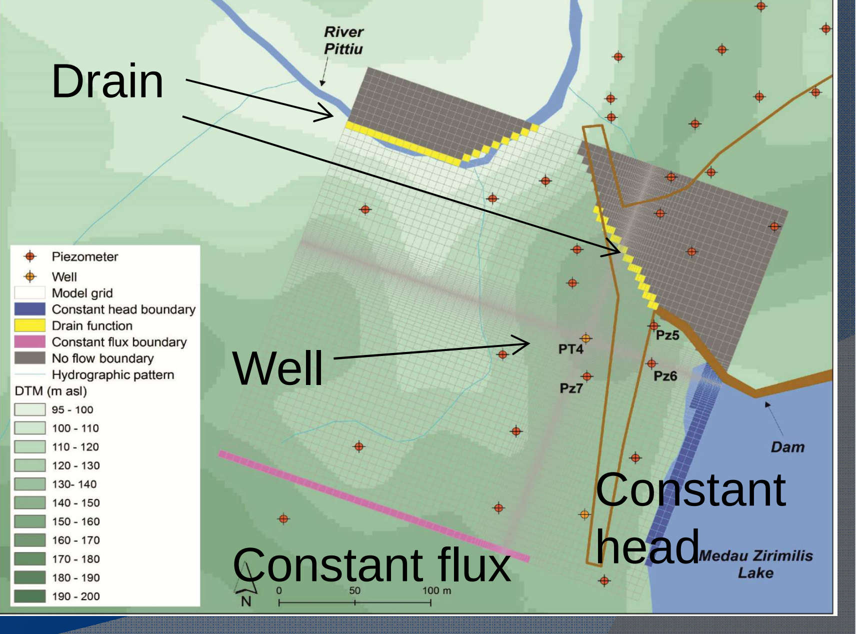
- K covered a lower range of values (10^{-6}–10^{-5} m/s)
- No particular trend was evident from the comparison of the values of K obtained for piezometers located in different directions from the pumped well
- The variation in the parameter is therefore attributable to the heterogeneity of the aquifer
- Higher values of T were found for the well near the fault

Finite differences transient flow model

A simplified numerical model was constructed in the western sector of the dam site, where a well tested during pumping tests falls and nearby the outcrops of the surface fracture survey.

Initial heads, geometry of the model, aquifer charateristics and boundary conditions were obtained from the investigations and from the conceptual model.





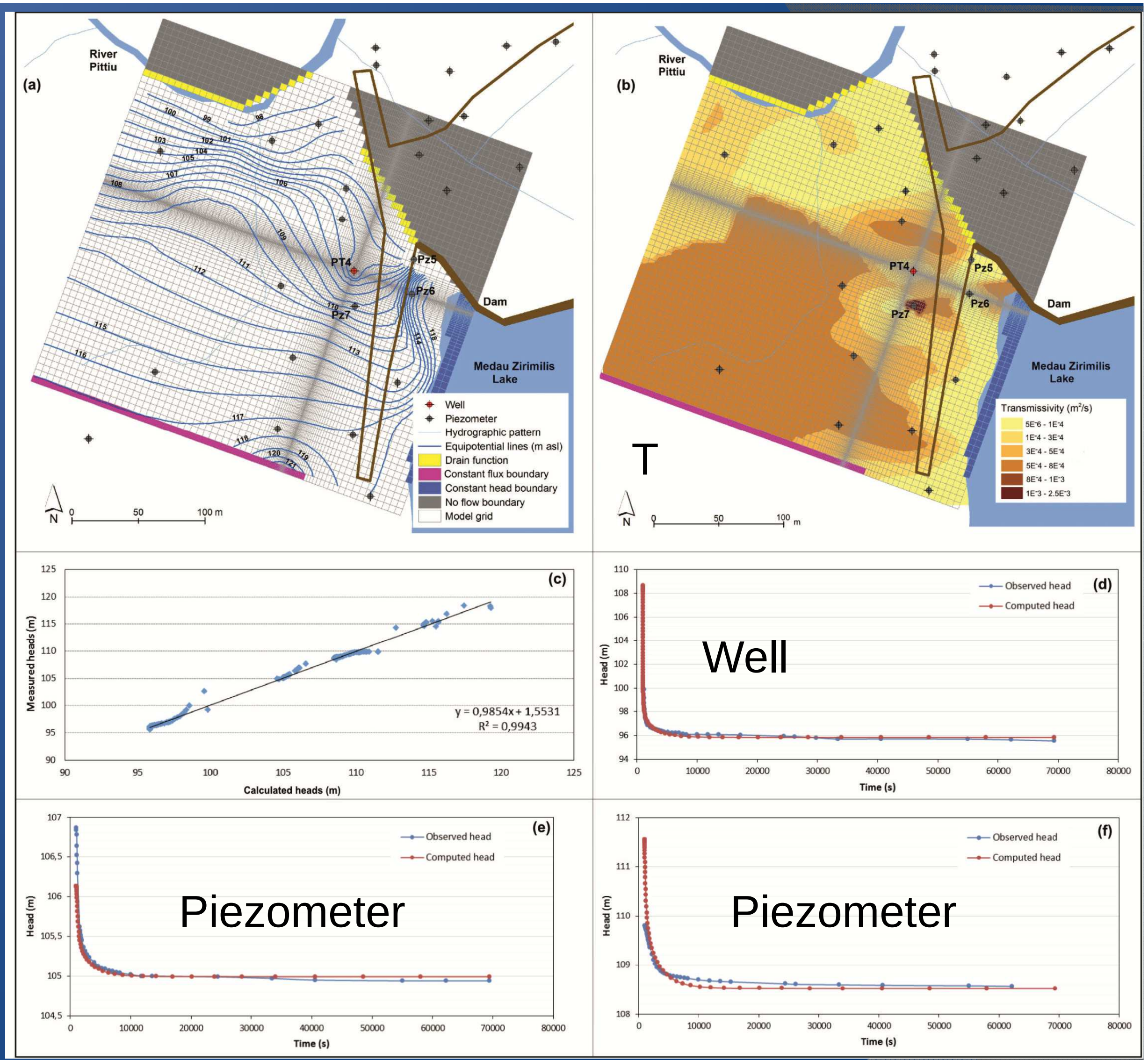
Calibration: trial-and-error and PEST 13.0

A first time period: steady-state calibration

A second time period: pumping from the well at a constant rate for 19 h

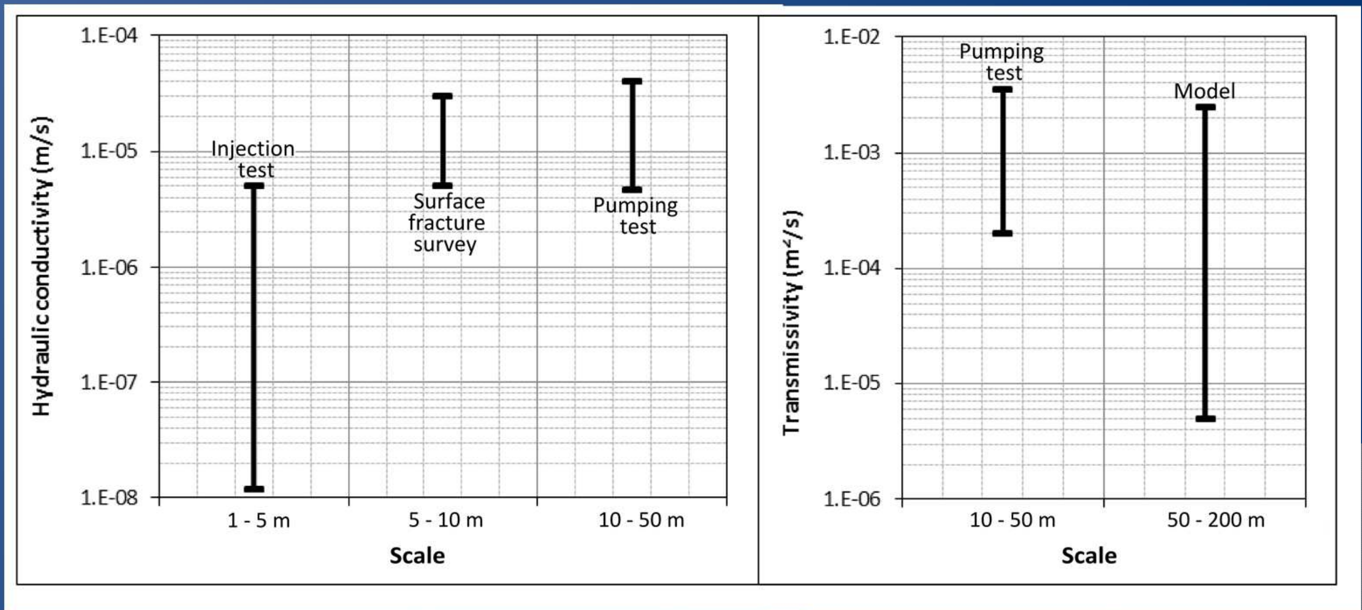
Transient data were calibrated for the pumping well and two piezometers.

Calibrated ranges of T: 5.0×10^{-6} - 2.5×10^{-3} m²/s.



Concluding remarks

- The results of the field investigations together with the model output would encourage the equivalent porous approach.
- The estimate of transmissivity resulting from the model highlighted a range of values higher than those resulting from the pumping tests.
- Four orders of magnitude of transmissivity obtained from the model compared with two orders of magnitude from the pumping tests, highlight a higher hydraulic heterogeneity of the aquifer, in agreement with the results of the injection tests.



Concluding remarks

- The characterization of the metamorphic rocks of the area studied herein demonstrated that the continuum medium approach can be used when a dense network of discontinuities exists.
- The multi-scale approach is recommended for investigating the hydraulic heterogeneity.
- The examined hard rocks fall in the classes III and IV of the transmissivity classification (Krasny 1993): from low to intermediate transmissivity magnitude.
- This aquifer, commonly believed to be not productive, may be of interest for local water supply.
- The most promising areas for well location correspond to valleys closed to faulted zones where transmissivity increases.
- A relative higher yield of wells is expected in case of boreholes inclined according to an angle which can be determined after the fracture characterization.
- A large extent of hard rocks in Sardinia (51 % of the regional area) and in Calabria (39 % of the regional area) together with a local scarcity of water resources imply a more rational use of these aquifers.

Merci de votre attention!