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# Integrated application of high-resolution shallow geophysics: aerial thermography and Ground Penetrating Radar on a spring barrier system

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***ABSTRACT*** Ground Penetrating Radar (GPR) and airborne thermography have been used for the location of buried spring barrier ponds and for the investigation of the shallow subsoil. Thermography has been selected for its ability to cover a wide area in a short time, the GPR has been chosen for the ability to distinguish, in great detail the presence of permeable layers composing the subsoil. Very positive results have been obtained by the use of the thermography in summer and wintertime to locate the “inverse” thermal anomalies determined by the presence of shallow groundwater; the subsequent GPR survey permitted us to identify a series of sand and gravel interbeddings responsible for the formation of the spring system.

## 1. Introduction

In the frame of the EU LIFE04-CAMI ENV/IT/00500 “Characterization of Aquifers by Integrated Methodologies” a series of shallow geophysical investigations have been carried out to identify the location of buried springs. The area of Torrate (PN-Italy) is, in fact, characterized by a number of buried springs outcropping in presence of depressions, trenches, or in particular situations related to geological variations. To protect this sensitive environment, it is important to detect and map the points where the groundwater approaches the surface; this is not an easy task due to the seasonal fluctuations and the large territory to be investigated.

Considering that springwater is warmer than the soil in winter and colder in summer, thus generating an inverse thermal anomaly, it was decided to apply a thermographic approach for the investigation of the area. On the other hand, it was also necessary to understand the buried geometry of the subsoil to determine the geological factors controlling the uprising of the groundwater.

Two airborne thermography surveys and two Ground Penetrating Radar (GPR) campaigns have been carried out to optimize the data collection and to benefit of thermal contrasts occurring in cold and hot seasons.

## 2. GPR methodology

The methodology is similar to that of normal radars: an electromagnetic signal formed by a wave train of selected frequencies is sent by a transmitting antenna to the object of the investigation, the reflected signals are detected by an Rx antenna, and processed to obtain an

Fig. 1 - The Control Unit GSSI SIR SYSTEM 2.

image of the target object (Annan and Davis, 1978).

The typical configuration of a GPR system is formed by a Control Unit, cables and antenna with or without odometer-encoder.

## 3. Data collection

The investigations have been carried out by a GSSI SIR SYSTEM 2 (Fig. 1) formed by:

- Control Unit (CU)
  Contains the electromagnetic power unit that generates the e.m. pulse and the wave train, permits us to set the amplification parameters and to select the recording time (investigation depth) as well as to set different acquisition and visualization parameters. It contains the data-recording unit (HD).
- RX-TX Antennas
  The antenna (transducer) transforms the e.m. pulse to a radar signal and sends it into the medium to be investigated, then receives the reflected wave and transmits it to the CU. The type of antenna determines the frequency of the signal.

Data have been recorded by 400 and 200 MHz antennas towed by a 4x4 vehicle at about 2-3 km/h, an automatic encoder permitted us to set a regular marker at 5-meter intervals and, more important, to have a regular and constant number of scans per meter to facilitate the processing of the signal and to avoid horizontal deformation (elongation or compression) of the section due to velocity variations (Telford *et al.,* 1990).

## 4. Location of the GPR profiles

The profiles, carried out during the first GPR survey were located in correspondence with the seismic line that the Istituto Nazionale di Oceanografia e Geofisica Sperimentale (OGS) carried out from the water catchments plant belonging to our Partner "Acque del Livenza" at Torrate, and develop southword on a trail parallel to the asphalt road. Two parallel profiles with different recording ranges (TWT) have been recorded in this direction (Olhoeft, 1990).

To obtain a precise reconstruction of the geometry of the subsoil an orthogonal E-W profile, has been recorded in correspondence to the south end of the N-S one (Fig. 2).

The sign, posted by OGS, has been used for a precise correlation of data between seismic and GPR surveys. The precise location on the map, permitted us to make an easy correlation with the thermography and other geophysical data.

The second GPR campaign was located in a different area due to the absence of any trace of spring waters and due to buried structures in the previous one (Duke, 1990). The GPR profiles (Fig. 3) were situated in correspondence with the northern area in front of the water tower; this area has already been investigated by thermographical airborne survey and high resolution geoelectric tomography (Sakayama *et al.*, 1983). The GPR profiles were recorded in N-S and E-W directions with a spacing of 25 metres orthogonally to the road, parallel to the fence.

During the data acquisition, reference markers were set at the sections in correspondence with the reference points, located on the surface by orange plastic indicators.

This campaign has been integrated by a further series of profiles in correspondence with the anomalies detected by the thermography and by excavations, that pointed out the presence of springwaters and a water table at less than 70 cm from the surface.

## 5. Results

The high resolution provided by this methodology permitted us to identify some typical elements of the subsoil and put in evidence the sedimentological differences between the shallower and deeper parts of the subsoil.

During the equipment calibration, different configurations were tested; during such tests, a depth of 9 metres was reached by using a 200 MHz antenna, but the data appear of acceptable quality only up to about 3-4 metres from the surface. Beyond this depth the signal presents a too high noise level. The limited penetration of the electromagnetic signal is determined by the presence of clay in the sediments that determines a series of interactions between the clay particles and the electromagnetic signal with the result of a strong signal attenuation.

By analysing the above mentioned effects, it was possible to identify the sub-surface layers of clay composed, of clay and silty-clay sediments that are characterized by a different reflection coefficient (Ulriksen, 1983).

They are not constant but are frequently interrupted by lenses having a different sedimentological composition with a higher content of coarse sediments such as sand and small gravels; these gaps are the locations of the water spring ponds (Fig. 4).

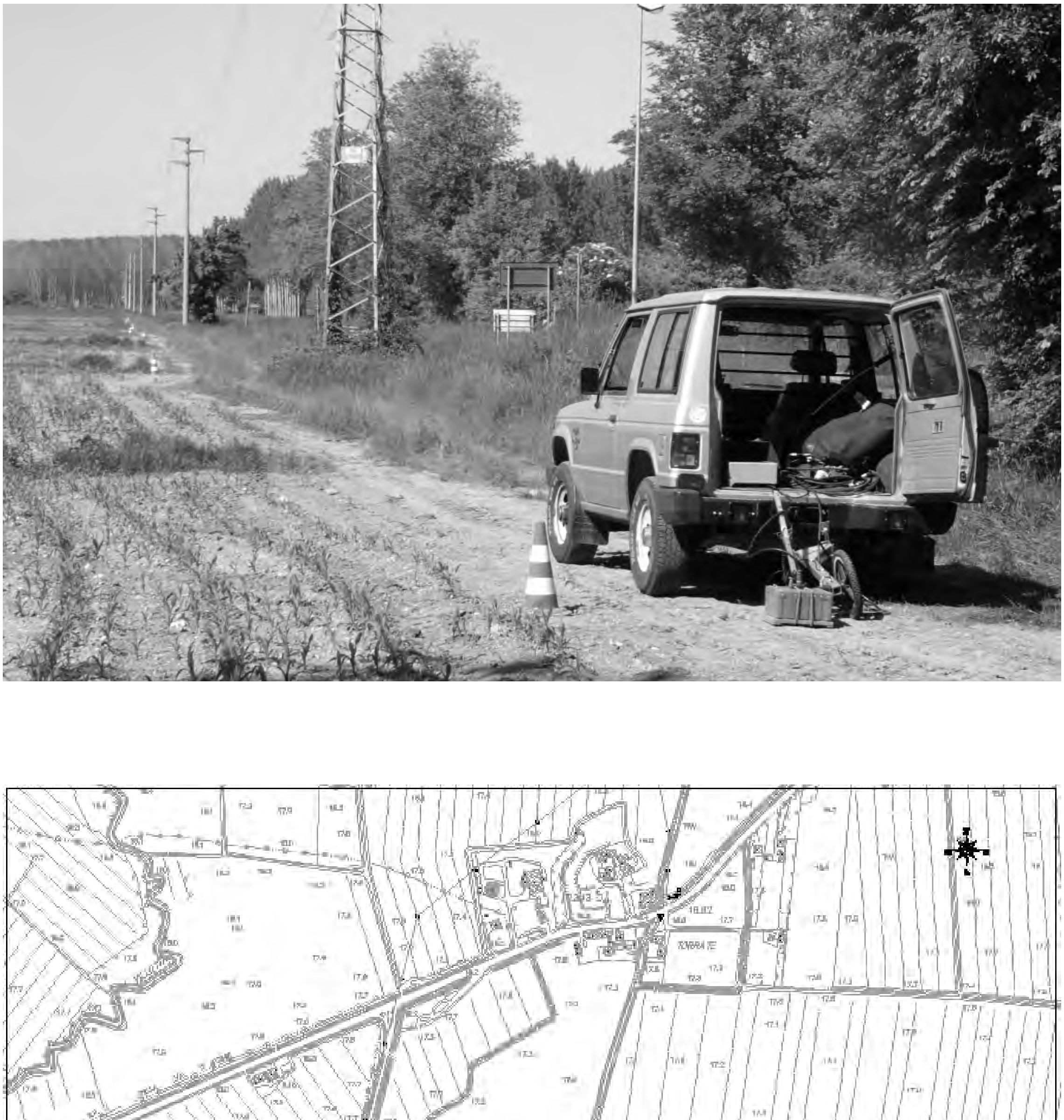

Fig. 2 - 1st campaign: a) execution of GPR profile; b) location of GPR profiles.

Fig. 3 - 2nd campaign: a) execution of GPR profile; b) location of GPR profiles.

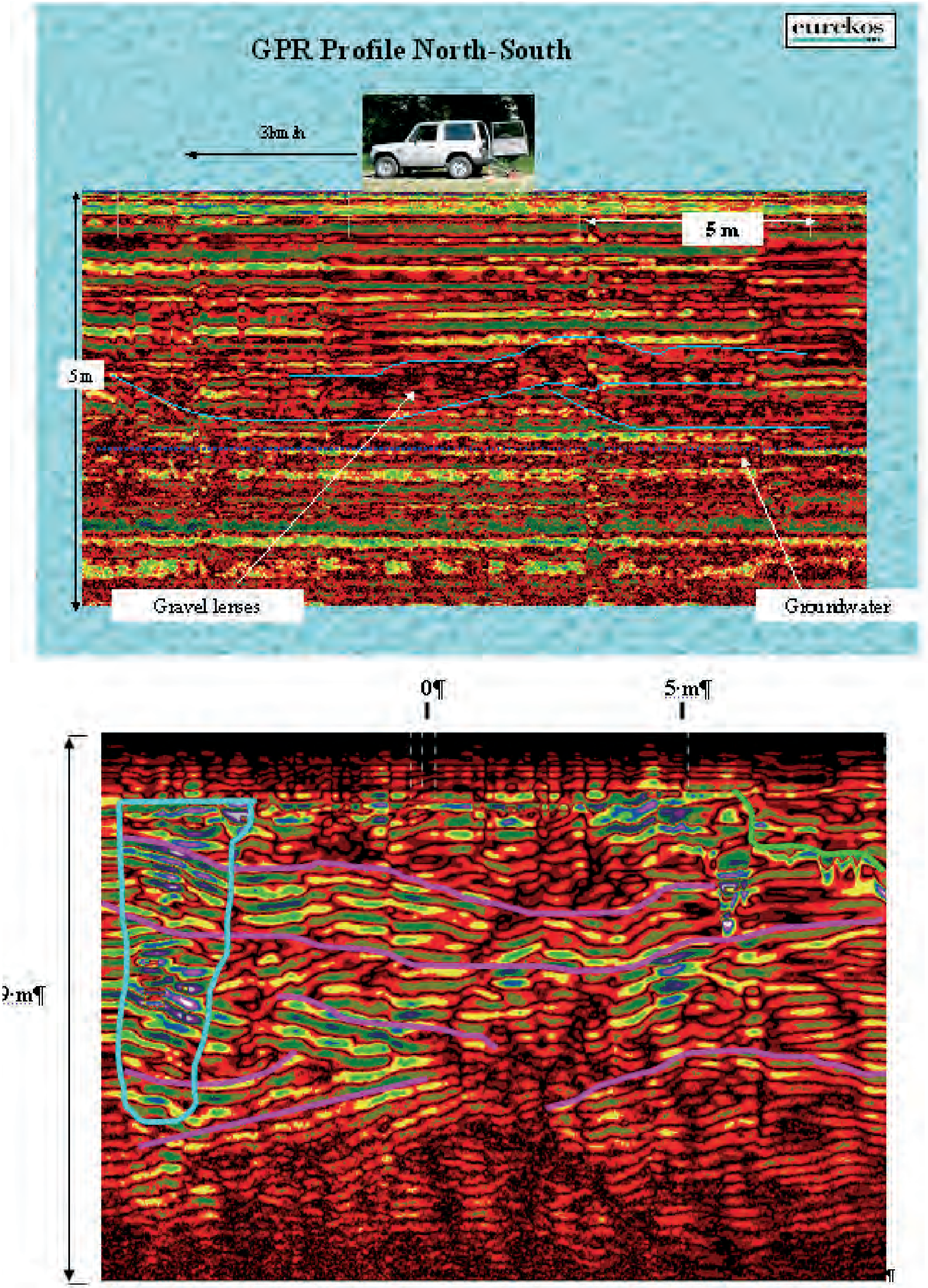

Fig. 4 - a) GPR profile N-S executed in the SE area. b) GPR profile T-10 after processing. In evidence the anomalies determined by clay layers (magenta), presence of spring water (cyan) and an old trench (green).

## 6. Thermography methodology

### *6.1. Methodology*

Two campaigns of thermography surveys have been carried out; the first one provided a general overview of the thermal anomalies, the second aimed at confirming the previous data. In fact, the presence in both campaigns of anomalies having opposite thermal behaviour in the same spot should be a confirmation of the presence of groundwater rising.

To improve the positioning of the photos and facilitate the reconstruction of the photomosaic, special "cold" reflectors made of aluminium foil, have been constructed and put on the ground on surveyed positions (Nowick, 2004; Walker, 2004).

### *6.2. Instruments*

The thermal investigation has been carried out by an infrared camera that detects infrared energy (heat) and converts it into an electronic signal, which is then processed to produce a thermal image and perform temperature calculations. The used one, ThermaCAM S65 (Fig. 5) is designed especially for scientific testing and general-purpose non-contact measurement.

The fly has been performed by a two seat ultra light aircraft Storch (Fig. 6).

Fig. 5 - The ThermaCAM S65.

Fig. 6 - Ultra light aircraft STORCH.

## 7. Camera specifications

### *7.1. Imaging performance*

| | |
|---|---|
| Spatial resolution (IFOV) | 1.3 mrad |
| Thermal sensitivity | 0.08°C at 30°C |
| Image frequency | 50/60 Hz non-interlaced |
| Electronic zoom | function 2,4,8 interpolating |
| Detector type | Focal Plane Array (FPA), uncooled microbolometer 320 x 240 pixels |
| Spectral range | 7.5 to 13µm |

### *7.2. Measurement*

| | |
|---|---|
| Temperature range | -40°C to +1,500°C (-40°F to +2,732°F) |
| Accuracy | ±2°C, ±2% of readin |

## 8. Data acquisition

An ultra light aircraft STORCH has been used because of its reliability and stability. The area has been covered differently by 4 E-W flight paths at an altitude of about 100 m (Fig. 7). The camera has been kept with an angle of about 40° from the horizon giving a good coverage of the area.

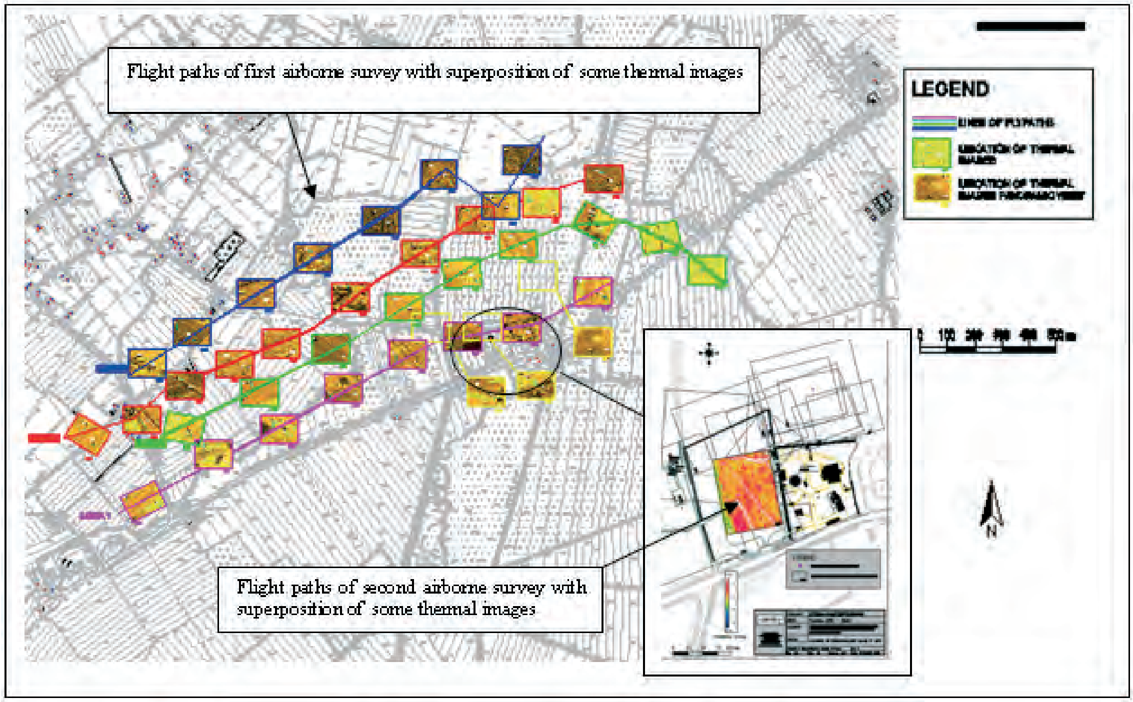

Fig. 7 - Ubication of thermographic images.

## 9. Data interpretation

The data have been processed by the dedicated software provided by the camera manufacturer using different thermal spectra and a T° interval (Fig. 8).

The attention was focused on the selection of anomalies detected during both surveys and special attention was paid to strong anomalies that could be determined by a rising of groundwater and not detectable by a single survey (Ward and Hohmann, 1988).

## 10. Thermography conclusions

It is possible to confirm that airborne thermography is a good and effective tool for the mapping of surface anomalies determined by the rising of the water table. Large areas can be surveyed in a short time but to optimise the survey its important to set up “turning points” and a reference “thermal marker” on the surface.

The survey has to be carefully planned in terms of atmospheric conditions; the timing of the survey has to be selected to have the strongest thermal anomaly.

It is important to survey with dry soil (soaked soil does not show any anomaly) and low or absent vegetation. The airborne platform should be stable and permit a low and slow flight; a two-seater side-by-side ultralight aircraft is a good solution.

The database of thermal images will permit further comparison of data with other

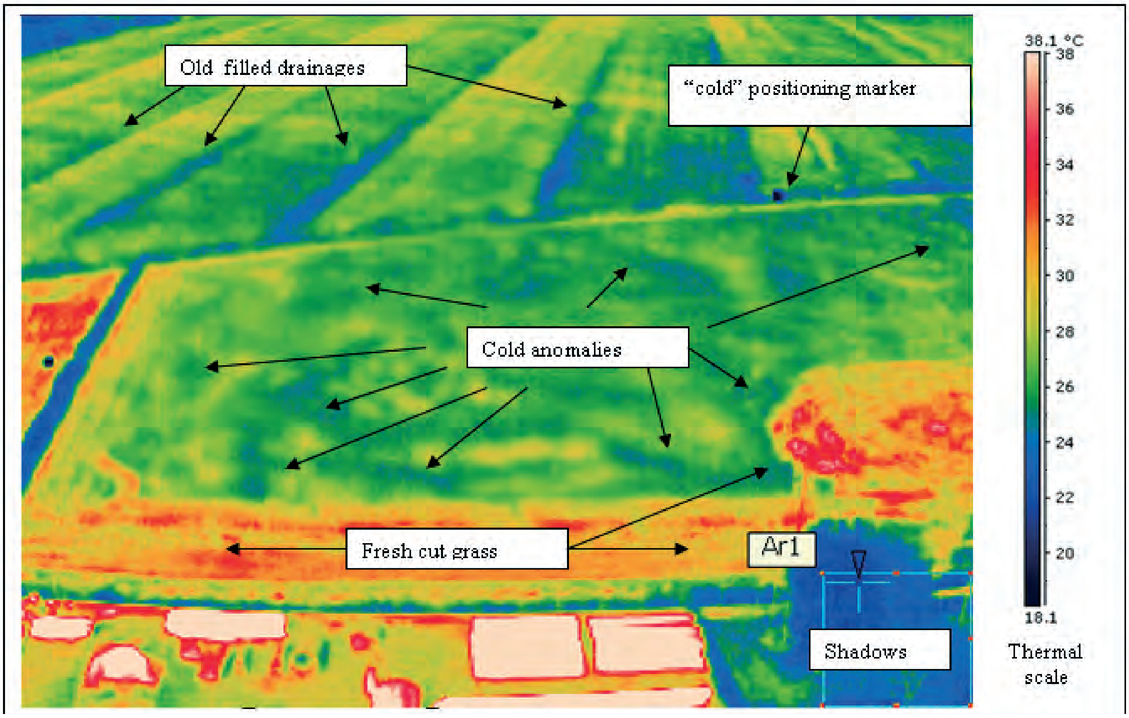

Fig. 8 - Thermal image recorded during summer survey.

methodologies and other thermal surveys. It is important, for this task that the "thermal markers" are precisely georeferenced.

## 11. Final conclusions

The study confirmed the possibility of locating thermal anomalies and correlating this situation with the GPR results, to locate the buried springs or the area where the groundwater is rising (Fig. 9).

The final picture, assembling all areas covered by the different methodologies and showing the locations of the main anomalies related to springs or shallows, is clear evidence of the obtained results.

The results related to the interdisciplinary approach have been very satisfactory; the superposition of the thermographic data with the GPR, can really provide very useful information and can minimize the extent of the surface to be investigated.

All objectives have been reached in technical terms and in terms of extension of surveyed area; actually the airborne survey proved by far much more effective then expected and is surely a good approach for the survey of areas of a few square kilometres.

Important facts are:

- to select the proper period of the season and of the day to obtain the strongest possible thermal contrast;

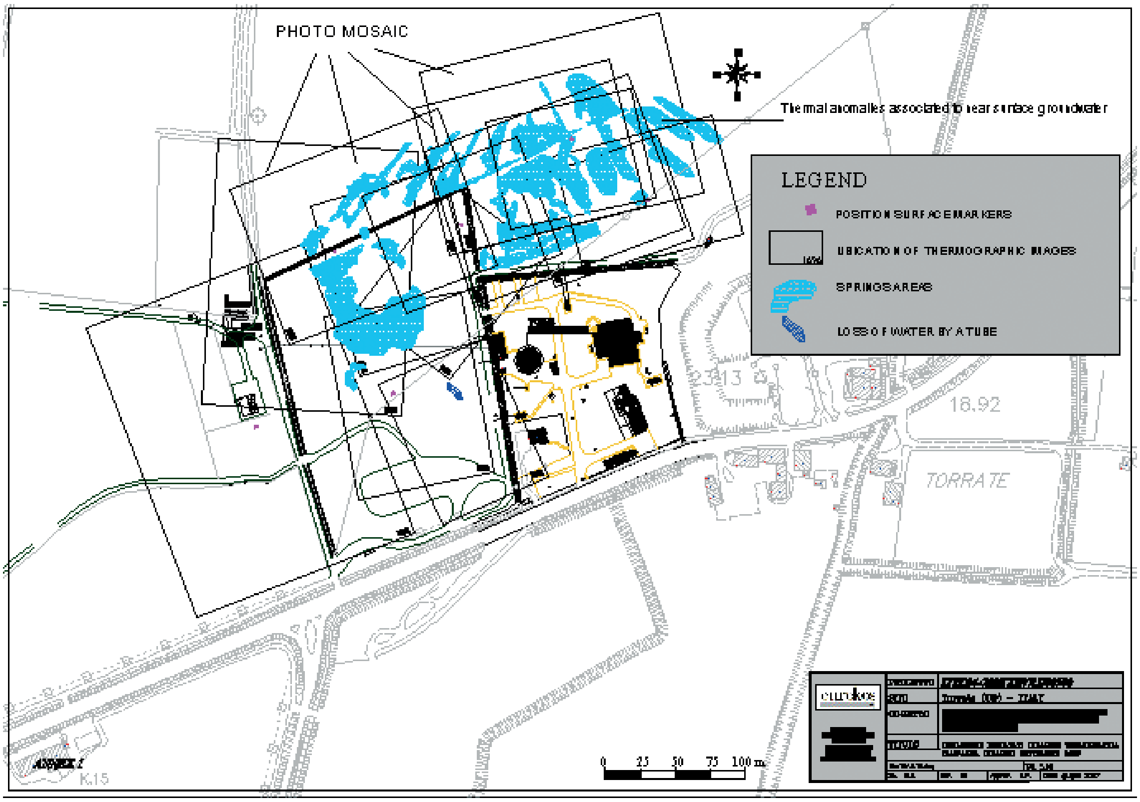

Fig. 9 - Ubication at the springs areas.

- to consider the type and height of the vegetation to avoid the "dumping effect" on the visibility of the anomaly;
- to set up precise "thermal markers" on the surface for the positioning of the images and the location of the subsequent GPR investigations;
- to perform the GPR investigations according to a grid of profile for a proper reconstruction of the subsoil geometry.

By dealing with the best standard practices and the above mentioned ones, the joint applications of airborne thermography and high resolution shallow geophysics (GPR) will provide very effective results both in technical and economical terms.

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