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Geophysical methods as support to aquifer recharge

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Abstract

In the framework of WAter Re-BOrn Project a large pond in Mereto (upper Friuli plain) was chosen as artificial recharge test site. Several geophysical investigations (GPR, Electrical Resistivity Tomography and High Resolution Seismic) were carried out to study and to characterize the vadose zone of this large infiltration basin. These geophysical integrated methods supplied us many information to characterize the vadose zone and the unconfined aquifer in the study area. The geophysical information greatly reduces the hydrogeological knowledge gaps and was used to improve the three-dimensional Finite Element numerical model to predict the effect of the artificial recharge.

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Keywords: GPR; Seismic; ERT; Aquifer Recharge; Hydrogeology

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1. Introduction

Since the nineteenth century the Artificial Recharge (AR) became an increasingly important means to solving water supply problems aquifers in several countries worldwide. The WARBO (WAter Re-BOrn) Project wants to improve a large-scale use of artificial recharge in Italy where water directives still strongly limit its application [1].

In the frame of the project three test sites were indicated for the AR. One of test was performed in Mereto di Tomba, located in the High Friuli plain on the left side of the Tagliamento river at 102.15 m asl. In this site a pond excavated in correspondence of an artificial channel for agriculture uses is present. The infiltration basin, built in the early 2000s, is about 5.5 m deep and 45×7 m^2 and contains approximately 1000 m^3 when water column is about 2.5

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m. In the site area six 70-m deep wellbores allowed us to obtain information about depth of the shallower structures. The supplied lithostratigraphies show an unconfined aquifer characterized by a 40-m thick top layer mainly composed of gravels, partially cemented and with the presence of clay fractions, overlying a fractured conglomerate horizon with a thickness larger than 30 m. We performed an integrated geophysical approach to better understand the soil characteristics. This technique is now widely used to solving geological, hydrological and environmental problems in geophysics. [2], [3], [4] and [5] carried out studies to assessment the hydrogeological conditions of single or multilayered aquifer system with geophysical integrated approaches. An AR project requires a good knowledge of the aquifer geometry and the surrounding geology. In this work we show as to detect and map the location, properties and geometries of geological units that could strongly affect the flux of the infiltrated water. This information provided valuable information for the hydrogeological modeling for the recharge test [6].

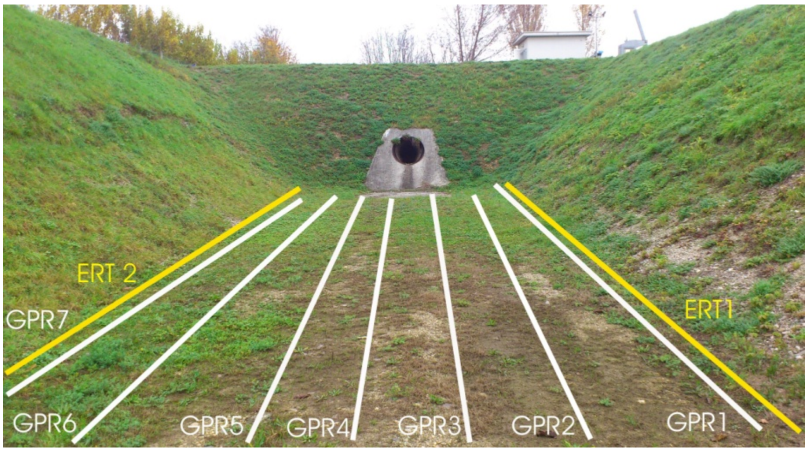

Fig. 1. Map of geophysical profiles. Seismic line is located on a road to the left out of the basin. All profiles start from inlet pipe.

2. Methods

In order to characterize the subsurface structures of the soil in the first hundred meters of the vadose area, three geophysical methods were employed. To investigate the first meters of soil into the pond, seven parallel Ground Penetrating Radar profiles, each 30 m long and 1 m apart, were collected (Figure 1). A georadar GSSI SIR2000, equipped with 200 MHz monostatic antenna, was used. The choose of 200 MHz instead of 100 MHz was done after a test profile that showed a comparable penetration, but a better resolution, as expected, with the higher frequency antenna. The trace length was 200 ns digitized at 1024 samples with a dynamic range of 16 bits. The spacing between adjacent traces was 10 cm. The GPR data shows a discrete signal/noise ratio. The processing was performed with REFLEXW focusing on gain (spherical divergence and the amplitude recovery, based on a mean amplitude decay curve) and filtering (Butterworth band-pass 70 – 300 MHz). In order to perform the time-depth conversion of the sections, some Common Mid Points (CMP) were acquired with the aim to define an electromagnetic wave velocity for the conversion. The CMP were performed using the georadar in bistatic mode [7]: the antennas were moved away of the same distance (10 cm) at every energization. After the semblance velocity analysis, a mean velocity of 8 cm/ns was used.

In order to obtain other information about the subsoil, two parallel Electrical Resistivity Tomography profiles were acquired on the bottom the tank (Figure 1). We collected the electrical data using a LGM 4 Punkt light up georesistivimeter produced by Lippmann Geophysikalische Messgerate. The geometry acquisition consisted of 60 electrodes spaced 0.8 m, for a total length of 47.20 m for each profile. To obtain a high resolution and to detect vertical resistivity boundaries, a dipole-dipole configuration was adopted. Electrical data were then inverted using the RES2DINV code. To investigate the subsurface structures until same hundreds of meters a 1 km long reflection seismic line in proximity of the pond was then acquired. The seismic source was a MiniVib IVI T-2500 mounted on a small truck, capable of generating a frequency modulated signal from 10 to 550 Hz. In this case we adopted a linear up-sweep from 10 Hz to 220 Hz with a tapering of 10 % and 12 s length. Seismic data were collected with a DMT Summit acquisition system equipped with 10 Hz single geophones. The receiver and shot interval was 5 m, and the data were acquired at a sample rate of 1 ms with an uncorrelated record length of 15 s. We didn't perform the correlation in field (real time inside Summit Boxes) because the profile was situated in proximity of a road with an air power line that produced a strong noise which degraded the signal during correlation. To attenuate this disturb we performed the predictive deconvolution method before correlation [8]. After pre-correlation deconvolution, data was correlated with the filtered ground force [9]. The processing steps in the pre-stack domain consisted of: geometry application, amplitude recovering and surface consistent, zero-phase filtering in the frequency domain, velocity analysis (semblance and common vertical stack), normal move out and stacking. To enhance final seismic section, a FX deconvolution [10] and an automatic gain control were applied. Finally depth conversion, using the velocities obtained by the semblance analysis, was applied. Seismic processing was performed using ECHOS (PARADIGM).

3. Results

Integrated geophysical surveys allowed us to obtain indispensable stratigraphic information about pond area. GPR highlighted the structures in the first meters. The first reflector detected in all seven profiles is located at a 1 m depth, while the second reflector is located at a depth between 2 and 3 m. This last discontinuity is undulating and non-continuous for the northernmost 20 m portion of the section (white dotted line in Figure 2), while southward its geometry appears more continuous and with a constant slope (white line in Figure 2). At a depth of 7 m, GPR detected other not continuous reflections. The presence of a very shallow formation, with a resistivity ranging from 500 to 750 Ωm, was picked out with ERT. This formation deepens at a distance of about 27 m from the northern boundary of the pond becoming thicker. The discontinuity detected in the GPR sections between 2 and 3 m is also identified by ERT. These could be closely to cemented gravels lens in the northern part of the section while can be associated with the base of a formation with resistivity ranging from 800 to 1500 Ωm. The highest resistivity zones detected in the northern part are representative of sedimentary bodies characterized by compact gravel, related to fluvio-glacial deposits. Below this, the resistivity decreases to values lower than 250 Ωm that could be connected to the presence of wet sand-clay lithologies (black dotted line in Figure 2). This wet material is the limiting depth of investigation of electromagnetic waves [11], too.

The analysis of seismic line (Figure 3) in proximity of the infiltration basin provided the subsurface features down to a 250 m depth. The depth stacked section evidences a first discontinuity at a depth of about 50 m. The depth range between 50 and 140 m is characterized by the presence of strong reflectors forming also unconformities. Below 150 m the ground surface no strong reflectors was detected until 250 m. Seismic interpretation was carried out based on the available lithostratigraphic information obtained from two piezometers wells. The stratigraphic analysis showed an upper 50-m thick formation composed of gravel with sand, silt, and clay fractions. An alternation of compact conglomerate and fractured conglomerate, with or without silt, spans the 50 to 150 m depth interval. The results of seismic profile carried out in this study showed that this features have a significant continuity in all study area. Geological studies in the Mereto area [12] supposed that the bedrock, which is characterized by Miocene deposits in sandstones facies, is located at a depth of about 250 m. This is in good agreement with the last strong reflector identified in the seismic section.

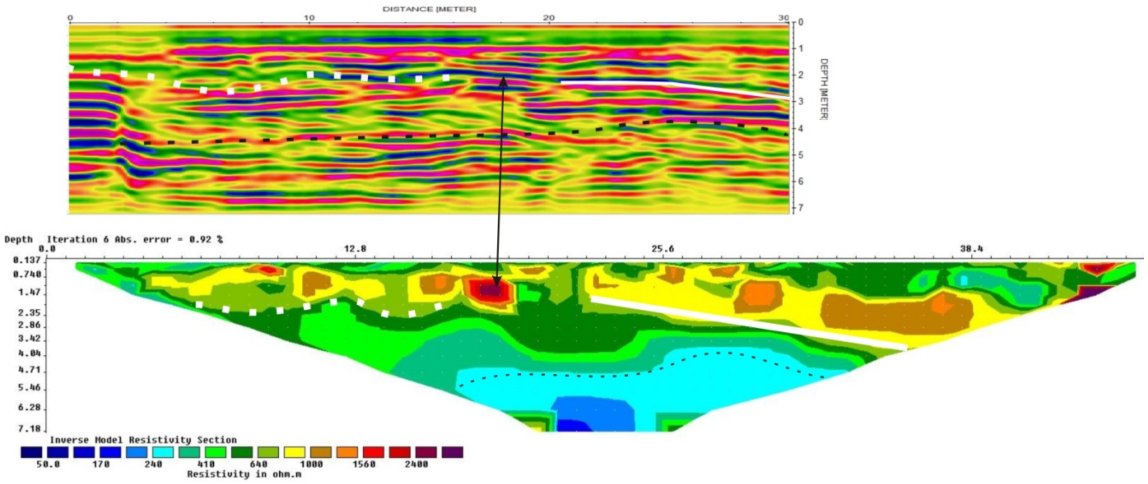

Fig. 2. GPR1 and ERT1 sections acquired along the same profile. The dashed line evidences a non-continuous and undulating discontinuity. The line is a limit of the presence a shallow formation that tilts towards South. The dashed black line shows resistivity values lower than 250 Ωm.

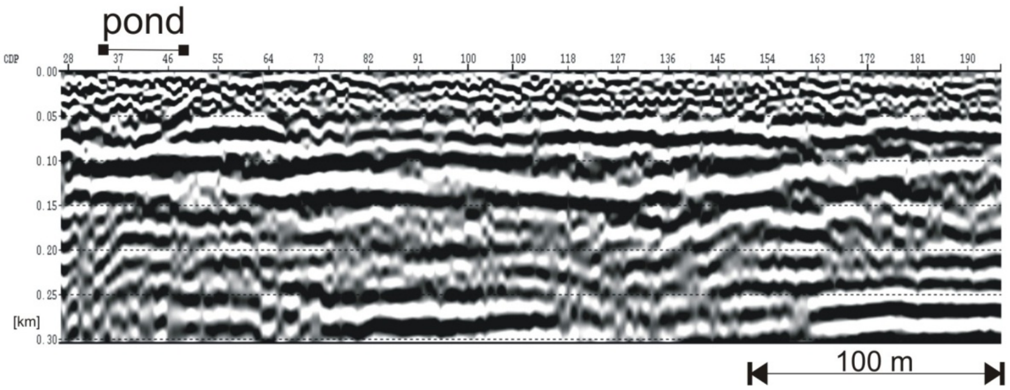

Fig. 3. A detail of seismic stack section. The first major discontinuity is identifiable at a depth of about 50 m. A strong reflector between 50 and 140 m characterize all profile. At about 250 m another strong reflector can be related to Miocene deposits in sandstones facies (bedrock).

4. Conclusions

The integrated use of GPR, ERT and High Resolution Reflection Seismic provided new and important information for the hydrogeological modeling for the recharge test of Mereto di Tomba. These methods have highlighted the presence of local heterogeneities within the major continuous geologic units. The geophysical study of an area is a fundamental step of AR, because a good knowledge of location, properties and geometries of inclusions, that strongly affect the fate of the infiltrated water, can improve the AR model.

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