DETERMINATION OF THE GROUND-WATER LEVEL BY MODERN NON-DISTRUCTIVE METHODS (GPR TECHNOLOGY)

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ABSTRACT. – Determination of the ground-water level by modern non-distructive methods (ground-penetrating radar technology). Ground Penetrating Radar (GPR) is now a well-accepted geophysical technique, which unfortunately in our country its less used. Historically, the development of GPR comes from the use of radio echosounding to determine ice thickness and it was only a short step to enlarge the domain of research such as permafrost, geological investigation (bedrock, sedimentology), environmental assessment and hydrogeophysical studies (under-ground water location, soil water content). The GPR method measures the travel time of electromagnetic impulses in subsurface materials. An impulse radar system radiates repetitive electromagnetic impulses into the soil. A bandwidth antenna is usually placed in close proximity and electromagnetic coupled to the ground surface. It detects and measures the depth of reflecting discontinuities in subsurface soils and other earth materials to within a few centimeters depending of antenna frequency. For over 30 years, GPR has been used extensively for hydropedological investigations. Our research aims to determine the groundwater to estimate the degree of evolution of hydro-geomorphological processes.

Keywords: Ground Penetrating Radar (GPR), Ground-water, geophysics, hydro-geomorphological processes.

1. INTRODUCTION

Ground Penetrating Radar method – GPR belongs to nondistructive geophysics, based on electromagnetic waves propagation in soil, rocks or other investigation mediums (concrete etc.) (Conyers, 2004). The original incentive for its development was for the army, who used it to detect burried mines and tunnels (Daniels, 2004). Today is a well known method used in different domains:

- Geological investigation: detecting bedrock, sedimentology (Davis and Annan, 1989; Beres and Haeni,1991; Bristow, 2003; Neal, 2004);
- Utility locating: electric lines, water drains lines, cable TV etc. (Al-Nuaimy et al., 2000; Lester et al., 2007);

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- Concrete detection: localization of reinforcing bars and metallic ducts, concrete thickness (Bungey, 2004; Barrile and Paccinotti, 2005; Chang et al., 2009);
- Hydrology (Doolittle et al., 2006; Ruffell, 2006; Lowry et al., 2009);
- Bridge and railway monitoring (Hugenschmidt, 2002; Narayanan et al., 2004);
- Environmental assessment and hydrogeophysical research: localization of under-ground storage tanks, soil contamination, soil water content (Mellet, 1995; Pyke et al., 2008; Gerhards et al., 2008);
- Road inspection: pavement structure analysis (Evans et al., 2006);
- Archaeology (Pérez Gracia et al., 2000; Conyers, 2004; Leucci et al., 2006);
- Forensics (Freeland et al., 2003; Ruffell et al., 2005);

GPR is widely used in various domain of research. In Romania it was and is still used in archaeology (Tencariu et al., 2010; Cotiugă et al., 2010). The following archaeological sites have been studied: Isaiia (com. Răducăneni, jud. Iaşi), Siliştea (com. Români, jud. Neamţ), Tinosu (jud. Prahova), La Pod (com. Bucşani, jud. Giurgiu), Tangâru (com. Stoeneşti, jud. Giurgiu), Trivalea Moşteni (com. Trivalea Moşteni, jud. Teleorman), Geangoeşti (com. Dragomireşti, jud. Dâmboviţa), the historical center of Botoșani city, with remarkable results that have been presented at symposiums and scientific exhibitions.

By this application we try to extend GPR domains of research: hydrogeology. In the following operating principles are exposed and the results obtained from scans (Băiceni–Muzeu Cucuteni gully slopes).

Romanian literature is reminiscent of shear or punctual measurements for ground-water but, unfortunatelly not fully explained. From this point of view only the foreign literature rises to the expected level: Al-Nuaimy et al., 2000; Barrile and Paccinotti, 2005; Băcăuanu, 1968; Băcăuanu et al., 1980; Beres and Haeni, 1991; Bristow and Jol, 2003; Bucur and Barbu, 1954; Bungey, 2004; Cassidy, 2000; Chang et al., 2009; Conyers, 2004; Cotiugă et al., 2010; Daniels, 2004; Davis and Annan, 1989; Doolittle et al., 2006; Evans et al., 2006; Freeland et al., 2003; Gerhards et al., 2008; Hugenschmidt, 2002; Jeffrey, 2000; Lester and Bernold, 2007; Leucci, and Negri, 2006; Lowry et al., 2009; Mellet, 1995; Naranayan et al., 2004; Neal, 2004; Pérez-Gracia et al., 2000; Pyke et al., 2008; Reynolds, 1998; Ruffell and McKinley, 2005; Ruffell, 2006; Sass, 2006; Tencariu et al., 2010 a,b etc.

2. THEORETICAL AND OPERATIONAL PRINCIPLES

GPR is a worldwide useful tool, which unfortunatelly in Romania is less used. (Daniels, 2004). GPR is efficient to detect objects at shallow depths. Best results are obtained under a smooth topographic surface and dry soils: sandy soils and gravels (Reynolds, 1998). Bad soils are muddy, clay or soils that contain salt water. (Fig. 1).

a. b.

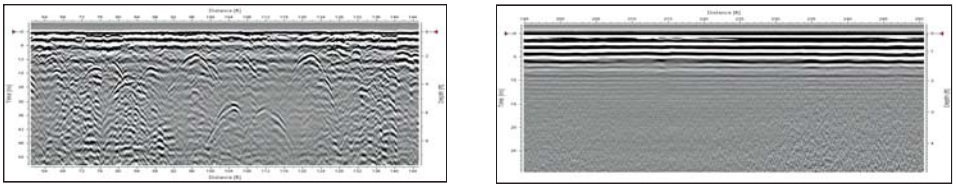

Fig. 1. ***The difference between good soils (a) and bad soils (b) for scans***

Tabel 1. ***Static conductivity and relative permittivity values for different materials - 100 MHz antenna (adapted after Conyers şi Goodman, 1997; Reynolds, 1997; Daniels, 2004)***

Material	**Static conductivity, σ_s (mS/m)**	**Relative permittivity, ε_{ave}**
Air	0	1
Clay – dry	1–100	2–20
Clay – wet	100–1000	15–40
Concrete – dry	1–10	4–10
Concrete – wet	10–100	10–20
Freshwater	0.1–10	78 (25°C)–88
Freshwater ice	1 – 0.000001	3
Seawater	4000	81–88
Seawater ice	10–100	4–8
Permafrost	0.1–10	2–8
Granite – dry	0.00 –0.00001	5–8
Granite – wet	1–10	5–15
Limestone – dry	0.001–0.0000001	4–8
Limestone – wet	10–100	6–15
Sandstone – dry	0.001–0.0000001	4–7
Sandstone – wet	0.01–0.001	5–15
Shale – saturated	10–100	6–9
Sand – dry	0.0001–1	3–6
Sand – wet	0.1–10	10–30
Sand – coastal, dry	0.01–1	5–10
Soil – sandy, dry	0.1–100	4–6
Soil – sandy, wet	10–100	15–30
Soil – loamy, dry	0.1–1	4–6
Soil – loamy, wet	10–100	10–20
Soil – clayey, dry	0.1–100	4–6
Soil – clayey, wet	100–1000	10–15
Soil – average	5	16

Depth of investigation is limited by the relative permittivity (ε_r) and the frequency of the antenna selected for the scanning (Malå Easy Locator, Operator's Manual). ε_r = permittivity of the material (ε) / permittivity of free space (ε_0), where the permittivity of free space is 8.8542 x 10^{-12} F/m. (Cassidy, 2000). (Tabel 1).

MALÅ Geoscience (Sweden) together with GSSI (USA) are world leaders in projection and producing Ground Penetrating Radar systems (GPR). Engineer first radar system since 1935, MALÅ Geoscience benefits by a professional experience for over 70 years, developing products covering a wide range of applications. They also developed softwares for data acquisition (GroundVision, MIRASoft, Easy Locator Monitor), data processing (RadExplorer, WinTomo, RadInter, Slicer) and data view (GPS Mapper, ObjectMapper, RoadWay Mapper).

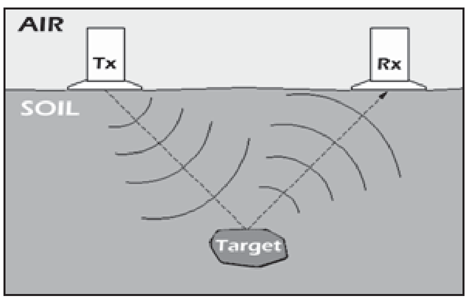

Fig. 2. ***Electromagnetic energy propagation from the transmitter (Tx) to receiver (Rx)***

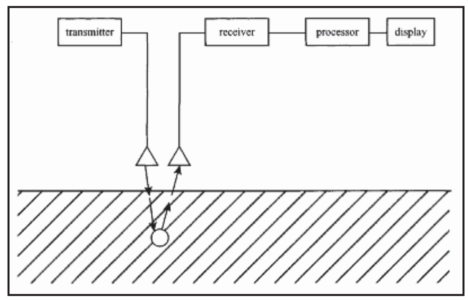

Fig. 3. ***Block diagram of generic radar system***

The relation between wave velocity and material properties is the basic principle for scanning with GPR. In this case the velocity is different for materials with other electric properties: a signal that has passed through two materials with different electric properties, at the same distance, will arrive back at different time intervals (Jeffrey, 2000). The GPR is capable to scan countinuously a significant area, in a relative short time. In principal, this technique revaluates the reflection produced and transfered in soil by the high-frequecy electromagnetic impulses. (Fig. 2, 3).

3. REGIONAL SETTINGS

The Băiceni–Cucuteni Museum gully is located in the south-western part of the Moldavian Plain, subdivision of the Moldavian Plateau. It cuts off the right slope of Cucuteni brook (13 km^2 surface of basin and 11 km in length), left affluent of Bahlueţ river (551 km^2 surface of basin and 41 km in length), at approximately 1 km NE from Cucuteni village, situated at 55 km from the city of Iaşi, 8 km NE from the city of Târgu Frumos, 35 km from Paşcani (Fig. 4).

The main deposits belong to medium sarmatian (basarabian), with a thickness of approximately 1000 m, monoclinal structure, a general pitch of stratum of about 8-10 m/km NV to SE orientation. The basarabian sediments are mainly composed from an alternation of marl, sands and clay, between are injected layers of sand stone, oolithe limestone having a big thickness, especially in the north part of the Cucuteni village and in the wesern part of Băiceni village also.

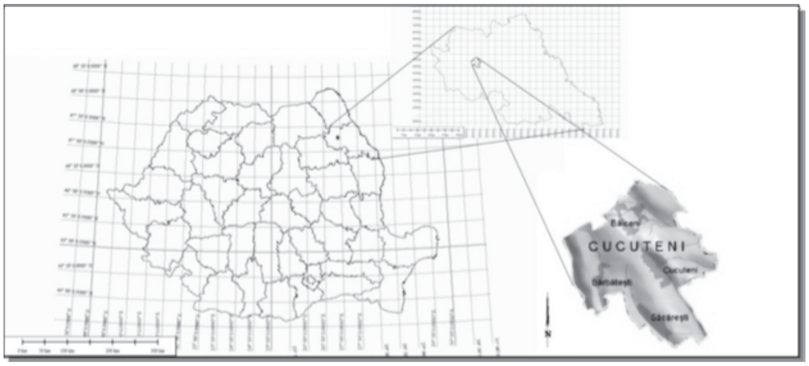

Fig. 4. ***Geographical location of study area***

Analyzing the medium monthly rainfalls we find a raise of these values from March (minimum) till July (maximum) followed by a decreasing. Here the tremendous downpours are characteristic. They can induce floods, accelerate soil erosion and snow ups during the winter. The air relatively humidity has an annual average of 71%. Aridity de Martonne value is 24,9. The annual rainfalls media is 510,7 mm at Cotnari meteorological station.

The main soils are represented by preluvosoils and luvosoils (located on the higher plateaus), followed by marnic phaeozems (with a high content of $CaCO_3$), chernozems and erodisoils (areas that are affected by landslides and gully's slopes).

4. DESCRIPTION OF FIELD EXPERIMENT

A RAMAC GPR X3M (Malå Geoscience) device and a Leica 1200 GPS. Measurements were taken with the 100 MHz antenna and following settings were made:

Antenna	100 MHz / Medium (Fig. 6)
Time Window	400.0 ns (20.25 m, 456smp)
Velocity	100 m/S/soil velocity
Acquisition mode	Wheel
Wheel type	Measuring wheel 100 MHz
Point interval	0.020 m
Parametrii semnalului:	
Sampling frequency	1065.08 MHz
Maximum time window	Medium
Autostacks	On.

We made a 48 m lenght profile, on the left side of the secondary gully to determine the depth of the ground-water level (according to topographic map scale 1:25000, 1983 edition, the ground-water level is situated at a depth of 4 meters near the area where the scan was made and 5 meters near Cotacu brook, located on the other side of the Tinos Hill) (Fig. 5).

After finishing the scan with GPR we used LEICA GPS 1200 (Global Positioning System) to georeference the measurements. How does it works? GPS– is using the satellites from the space as reference points to localize ground places.

System GPS 1200 is composed by a reference station that is positioned either in a point that has coordinates (GCP – Ground Control Point), or in a point that needs to be located and then radiates a strength signal for SmartRover. Leica SmartRover contains ATX1230 antenna + GNSS (triple frequency) RX1250 controller. The system heights about 2,7 kg. Leica RX1250 controller includes wireless technology (Bluetooth).

The reference was fixed on the GCP 2nd order Viteazul Hill (X = 645029.943, Y = 644429.686, Z = 340.000 m, STEREO 70 coordinates, Romania official cartographic projection), that emites signal for Leica SmartRover. In this way we could determine, with a high precision, the scan location.

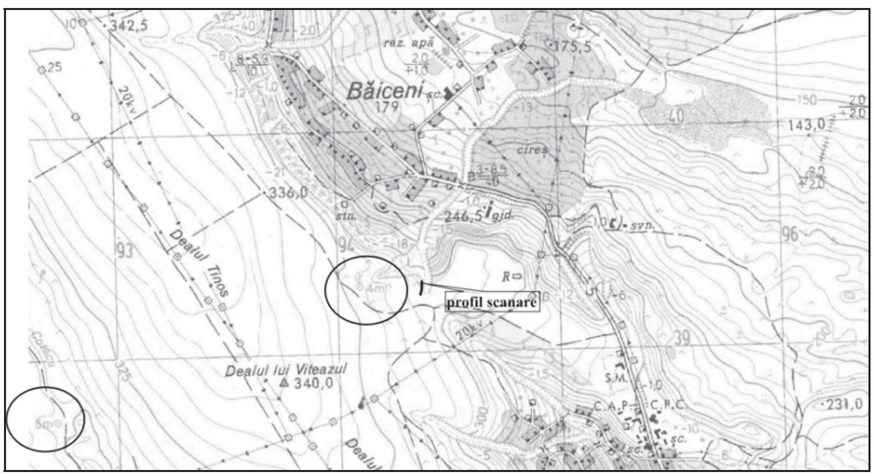

Fig. 5. ***Details of ground-water level in 1984***

5. RESULTS AND DISCUSSIONS

After the scans made with GPR Malå RAMAC X3M with 100 MHz antenna we obtained a 48 meters length profile and manage to determine de ground-water level as being at a depth between 8 to 10 meters (Fig. 6). The ground-water location can be distinguished in the scan image, but also on the photo. The images were „overlapped" for a better distinction. Scan data were also processed with red–blue filter and the results are the same as they were with the gray filter (Fig. 7).

Measurements with Leica GPS 1200 have positioned the scanning between following coordinates: X = 645659.657, Y = 644860.713 şi X = 645662.605, Y = 644908.865, STEREO 70 system and 47° 17´ 14.4933´´ Lat. N, 26° 55´ 32.9680´´ Long. E şi 47° 17´ 16.0496´´ Lat. N, 26° 55´ 33.1642´´ Long. E, in WGS 84.

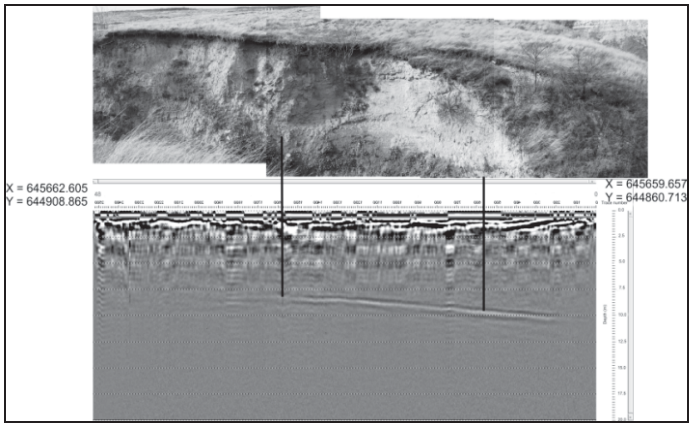

Fig. 6. ***Ground-water location (gray)***

One of the lowering ground-water explanations, unlike year 1983, could be found in location, at about 200 meters from the gully slopes, of 3 tubes for water captaion. Those tubes were placed there to reduce the amount of water that enters into the gully. In this way the erosional process is controlled.

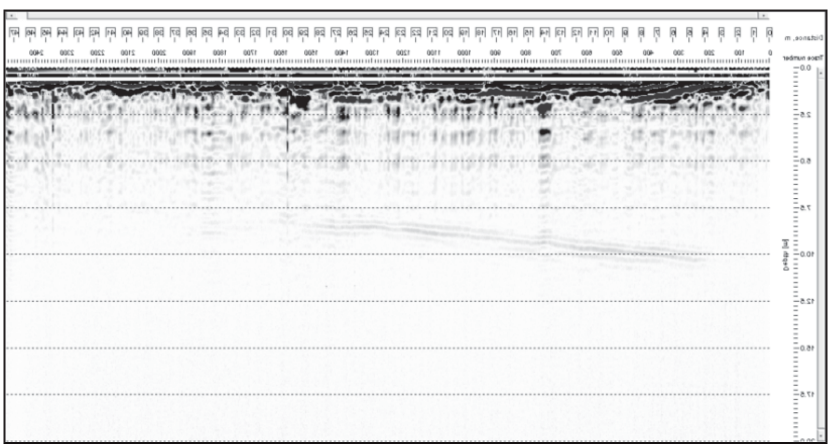

Fig. 7. ***Ground-water location (red – blue)***

The ground-water level may vary depending on the season, and that's why we will take another measurements in each season for a long period of time.

This scan was made in November 2010 and it perfcts the measure and monitoring system of the underground water resources.

6. CONCLUSIONS

GPR is efficient to detect objects at shallow depths. Depth of investigation is limited by the relative permittivity and the frequency of the antenna selected for the scanning.

The relation between wave velocity and material properties is the basic principle for scanning with GPR.

After the scans made with GPR Malå RAMAC X3M with 100 MHz antenna we obtained a 48 meters length profile and manage to determine de ground-water level as being at a depth between 8 to 10 meters.

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