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THE ASSESSMENT OF HYDROGEOLOGICAL PARAMETERS OF AQUIFER WITH THE USE OF MAGNETIC RESONANCE IN LOWER SILESIA (SW POLAND)

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Abstract: Magnetic Resonance Sounding enables the assessment of the water content, permeability and transmissivity of different layers of rock while remaining relatively cheap. MRS results obtained in five areas of Lower Silesia (south-western Poland) and verified by boreholes seem to substantiate a claim that this method can be used to successfully identify inflow zones. The results of researches showed, that water content and hydraulic conductivity depend on the type of deposits and the depth range from <0.5 to 38% and 0.001 to 30 m/d. In the case of aquifers minimum values were increased to 3.5%, and 0.17 m/d. The transmissivity obtained from pumping test was in the range 7-8691 m^2/d. The MRS transmissivity ranged from 1-86 m^2/d (fractured rock) to 14-15552 m^2/d (porous rocks). The assessment of hydrogeological parameters of aquifer with the use of magnetic resonance showed that without calibrations process MRS method allows a low cost and non-invasive is able to estimate the hydraulic conductivity (or transmissivity), water content, thickness of the different layers, etc. of aquifers in localized favourable configurations (non-urban areas). In the case of high water content aquifers, the MRS analysis suggests that hydraulic conductivity and transmissivity are lowers about 20%, while in low or medium water content aquifers MRS hydraulic conductivity value is about 40-80% higher. The location meets the requirements of MRS measurements and knowledge of one parameters makes it possible to determine the next parameters with a much higher accuracy.

Keywords: hydrogeological parameters, magnetic resonance sounding (MRS), SW Poland, water content, groundwater reservoirs

1. INTRODUCTION

The magnetic resonance sounding (MRS) has been increasingly used in hydrogeological research. It is a surface geophysical method and enables non-invasive detection of aquifers (Legchenko & Valla, 2002; Roy & Lubczyński 2003b; Legchenko et al., 2004; Lubczyński & Roy, 2004). The experience of various teams working with the use of MRS in the last two decades shows that this geophysical method can be employed when determining groundwater content and transmissivity of aquifers in the top 150m.

The literature evaluating the use of MRS in defining aquifers and groundwater content is scarce. The first publications describing the methodology of research and its possible uses (Turshkin et al., 1994; Legchenko et al., 2002; Lubczyński & Roy, 2003, 2004) were followed in 2004 and 2005 by the articles which compared the results to those provided by drilling, pumping tests and laboratory studies. The works of Mangisi (2004), Lachassange et al., (2005) and Vouillamoz et al., (2005) served as the basis for a more thorough analysis of the strengths and weaknesses of MRS. Emphasis was laid on the necessity to correlate the hydrogeological parameters and the MRS results. Otherwise, aquifers within the same geological setting would have to be compared qualitatively. The methodology of research also assumes that MRS is inapplicable in areas affected by strong artificial or natural electromagnetic disturbances. On the other hand, one of the main goals of the MRS is defining hydrogeological conditions so as to determine optimum locations for the construction of wells, as well as to assess the groundwater content of spoil tips. Field conditions only allow such measurements to be performed in areas which have not yet been properly mapped, where electromagnetic disturbances cause noise that is considered as an observational error. In such cases, the use of this method is limited to determining the depth and thickness of the layer holding the most water. Results obtained in such a way often prove satisfactory to potential investors, partly due to the low cost of performing the measurements. The MRS method has proven useful to this end, without the necessity to carry out inversion, while going through the strict process of calibration (Lachassange et al., 2005). In urban areas, on the other hand, where there is a large amount of electromagnetic noise, it is necessary to implement methods of reducing the disturbances. This, however, limits the scope of research by reducing the depth at which hydrogeological conditions can be evaluated (Trushkin et al., 1994; Plata & Rubio, 2002).

In the world literature the application of magnetic resonance occurs in the context of the supplement the hydrogeological data coming from other sources, for example: pumping test, geophysical resistivity method, boreholes geological data. One of the examples is the use of magnetic resonance sounding to clarify the hydrogeological parameters of the aquifer in order to construct and calibrate hydrological model of Carrizal River catchment in Spain (Baroncini-Turricchia et al., 2014). On the African continent (SW Niger) the results of hydrogeological parameters of sandstones were presented based on pumping test and MRS. The observed fit between the MRS and pumping test data was reasonably satisfactory, considering the natural geological conditions of the experimental dataset (residual error of 60%) (Boucher et al., 2009). The same was done for transmissivity evaluation of alluvial aquifers in Spain (Plata & Rubio, 2008). MRS results were compared with geological data of the boreholes and the pumping tests. This methodology also allows getting a calibration coefficient.

In order to evaluate the applicability of the magnetic resonance sounding method and its accuracy in estimating the hydraulic conductivity of sedimentary aquifers, MRS researches were conducted in Denmark. MRS results were compared with the aquifer parameters defined by geological description of boreholes (Chalikakis et al., 2009).

MRS studies are also used as a complement to other geophysical surveys. An example is research of groundwater recharge in southern India. The results of MRS were used as a complement for geophysical resistivity method. A combination of resistivity method with MRS provides valuable information on structure and aquifer properties respectively, giving a clue for a conceptual model of the recharge process (Descloitres et al., 2008).

The articles describe the hydrogeological conditions of Poland using the MRS methods have not been published yet. The results of studies conducted by the authors are the first synthesis of the possibility of using MRS to identify the hydrogeological conditions in Poland. The aim of the research was to verify the suitability of MRS in assessing groundwater content and the hydraulic conductivity in porous and fractured rocks in Lower Silesia (south-western Poland). Having recorded and interpreted the measurements, the results were compared with those obtained in nearby boreholes.

2. METHODS

This method involves exciting the hydrogen protons of the pore water with an artificial magnetic field that oscillates with the local Larmor frequency of the hydrogen protons. The Larmor frequency value depends on the intensity of the Earth's magnetic field at the local survey area. In MRS, the magnetic field is generated by a circular, square or octagonal antenna loop on the ground that is energised by an alternating current. The size of the wire loop (50-150 m) depends on the depth of the target aquifer. The vertical resolution is highest close to the surface (up to a few meters below the ground) and lowest at large depths; at depths greater than approximately half the loop size, aquifers cannot be defined without additional information from, e.g. boreholes (Roy & Lubczyński, 2003b; Legchenko et al., 2004). A current oscillating at the Larmor frequency is passed through the transmitter loop to create a magnetic field. When the current is abruptly turned off in the transmitter loop, the loop acts as a receiver that records the secondary magnetic field amplitude produced by the protons going back to their original state. The secondary magnetic field fades with time (Legchenko et al., 2004; Descloitres et al., 2008). The sounding is performed using several current steps, while the pulse duration is kept constant. The resulting sounding curve is analysed to estimate the depth and thickness of the aquifer, the MRS free water content and the MRS hydraulic conductivity (Lubczyński & Roy, 2005; Vouillamoz et al., 2005).

Direct parameters derived from MRS are the water content (θ_{MRS}) and the relaxation times (T_1 and T_2) versus depth (Legchenko et al., 2004;

Lubczyński & Roy, 2004). θ_{MRS} is the ratio between the volume of water (MRS readings) and the total sampled volume. T1 and T2 are related to the exchange of energy between protons and their environment and between the protons themselves. Both T_1 and T_2 are linked to the mean size of the pore containing water (Legchenko & Valla, 2002). θ_{MRS} and T_1 are used to estimate the hydraulic conductivity and the transmissivity of aquifers. The hydraulic conductivity of aquifers can be estimated as $K_{MRS}(z) = C_p\omega(z)T_1^2(z)$, where ω and T_1 are respectively the water content and the relaxation time derived from MRS measurements. For sandy aquifers, as well as for aquifers composed of weathered and highly fractured rock, the hydraulic conductivity can be estimated using the same value of the empirical constant C_p=7.0x10^{-11}, where the units for ω are (%) and for T_1 (msec) (Legchenko et al., 2004).

Where possible, the MRS parameters can be correlated with the aquifer characteristics through a calibration procedure employing pumping tests.

The conditions required for MRS measurements include a stable magnetic field, low magnetic susceptibility and a low level of electromagnetic noise. The most severe limitation to the MRS system is its sensitivity to man-made and natural noise, such as power lines, industrial activity, houses, radio aerials, pumps, motors, buried pipes, fences, cyclic solar activity, rain and magnetic storms (Roy & Lubczyński, 2003b). The use of other loop shapes instead of the square loop brings a significant improvement in noise reduction, albeit at the cost of shallower research depth (Trushkin et al., 1994).

A more complete description of the MRS technique and the determination of hydrodynamic parameters from MRS measurements is given by Legchenko & Valla (2002), Legchenko et al., (2004), Roy & Lubczyński (2003b), Lubczyński & Roy (2004), Mohnke & Yaramanci (2008).

A commercial version of the MRS technique called NUMIS LITE by Iris Instrument was used in fieldwork. This version is a reduced power version of NUMIS PLUS, designed for shallow water investigations (about 50 m). The NUMIS instrument consists of the following units: one AC/DC converter with a tuning box used to programme a variable amount of electric energy to produce the loop excitation current in the form of required pulse moment (Q); the main MRS unit used both for the AC loop excitation and acquisition of the signal; a reel of copper cable used to layout the loop, AC current loop of 60-metre long side; a high capacity rechargeable battery used to power the system and a normal PC laptop for overall system control, data recording and processing. For the inversion and interpretation of the MRS data, the 1D Samovar was used.

3. STUDY AREA

Research involving MRS was conducted in south-western Poland, in the Province of Lower Silesia (Fig. 1). Three test sites were singled out, varying in geological structure and land use strategies. In each one, two locations with low noise levels were chosen as the most suitable for carrying out measurements. Sounding was done at each of these locations. The first test site was an area where the aquifers formed numerous, mostly shallow groundwater bodies in fluvioglacial and fluvial formations. The second one included the Quaternary aquifers of Bogdaszowice – Radakowice, while the third test site was established across the terrain made primarily of crystalline rocks.

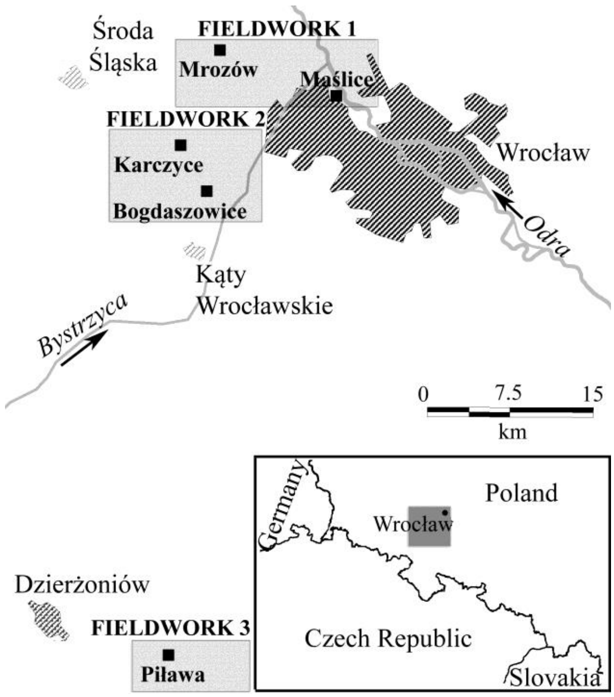

Figure 1. Location of MRS measurements

The first test site, characterised by shallow aquifers in fluvioglacial and fluvial formations, was located in the town of Mrozów and the Maślice estate (fieldwork 1 - Fig. 1). In Mrozów, the sounding point was set up in a field, 300 m from the nearest buildings. The useful aquifer was found in Neogene sediments, at a depth of about 14 m. These are unconfined or confined groundwaters, with groundwater table stabilisation occurring at a depth of 7 – 12 m. Its thickness ranges from 4 to 30 m and the hydraulic conductivity varies between 3 – 40 m/d. Transmissivity fluctuates wildly, from 9 – 611 m^2/d, while potential well discharges vary between 120 and 300 m^3/d, with the drawdown of about 2 m (Kiełczawa et al., 1997). Quaternary, several metres thick clay layers in the form of semi – and non-permeable rocks can be found in the cover. At the bottom of the aquifer are sedimentary rocks belonging to the Fore-Sudetic Monocline.

The second sounding point was set up in the suburban estate of Maślice, near a closed landfill and several hundred metres away from the closest buildings and roads. The area is a Holocene floodplain of the river Odra. The Quaternary aquifer lacks isolation and is composed of alluvial deposits (sand and gravel). The free water-table is located very closely to the surface, at a depth of 0.1 to 5 m. The thickness of the aquifer ranges from 5.1 to 10.7 m, the hydraulic conductivity varies between 9.7 – 90.7 m/d, and transmissivity figures fall between 22 and 662 m^2/d. The potential well discharge ranges from 240 to 720 m^3/d (Kiełczawa et al., 1997). The large depth of the aquifer is connected, as in the case of Mrozów, with fine-grained fluvioglacial sands which occur at depths of several metres (Fig. 2).

The second test site (fieldwork 2 - Fig. 1), located within the Fore-Sudetic block, is characterised by Quaternary and Neogene multi-aquifer formations, which remain in direct hydraulic contact with each other (Mroczkowska, 1997). Soundings included the Quaternary, trough-shaped Bogdaszowice-Radakowice aquifer. It is a deep rift, whose thickness exceeds 100 m, filled with sand and gravel sediments. It is an aquifer isolated from the surface by sandy clays whose thickness ranges from 7 to 40 m (Fig. 3). In most of the area, the Quaternary formation is confined and recharged through the infiltration of precipitation, from river beds and through lateral recharge from the Tertiary formation. In the vertical profile, an increase in depth corresponds with an increased contribution of coarse fractions. The water table is characterised by favourable hydrogeological parameters (k = 31 - 106 m/d, hydraulic transmissivity T = 2466 - 9352 m^2/d, elastic storage coefficient μ = 0,0026 ÷ 0,00054). Potential well discharges are around 200 m^3/h, with the drawdown of 2 – 3 m (Mroczkowska, 1997). The Neogene aquifer is connected to a multilayer complex of sandy and gravel deposits, whose thickness ranges from several to more than 70 m in argillaceous rocks. Owing to the depth at which it occurs, it has not been covered by MRS. The research in Bogdaszowice was conducted 100 m from the access road to the village and several hundred metres away from the closest buildings. The Karczyce point was located on farmland, approximately 200 m from a road connecting the two villages.

The third test site was located in the central part of the Sudetian Foothills, about 1.5 km north of Piława Górna (fieldwork 3 - Fig. 1). The area is located within the Fore-Sudetic fragment of the Sowie Mts., which is composed primarily of diversified metamorphic rocks such as migmatite and gneiss, as well as fragments of amphiboles (Cymerman & Walczak-Augustyniak, 1986). The Sowie Mts. metamorphic rocks are covered with a paradoxical combination of Neogene and Quaternary sediments. Groundwaters are represented by Proterozoic multi-aquifer formations and collect mostly in gneiss. Within these formations, two aquifers are considered useful: the upper aquifer in the sub-surface waste layer, characterised by free or slightly confined waters and lacking natural isolation, and the isolated, confined lower aquifer, associated with deeper water circulation within cracks, fissures, fractures and other forms of tectonic discontinuity in crystalline rocks. Groundwater within the sub-surface layer serves as a source for most springs, water capture by drains and water intake with induced infiltration. Water from the lower, deep-circulation zone is drawn by individual deep water wells. Generally, it can be assumed that in crystalline gneiss formations, useful aquifers can be found at depths of 15 – 50 m. The hydraulic conductivity calculated after pumping tests varies from 0.06 – 1.1 m/d, which gives a mean transmissivity of the exploited aquifers of approximately 15 m^2/d (Kiełczawa, 2000). The research was conducted 1.5 km north of Piława Górna, next to a working quarry of crystalline rocks.

4. RESULTS

Two soundings were carried out in the first test site: the village of Mrozów and the Maślice estate in Wrocław. On both occasions, the number of readings and stacks were set at 40, but owing to noise, it was decided that the depth of the sounding in Wrocław would be 25 m. In Mrozów an aquifer, 11 to 23 metres thick, was identified at 50 metres below ground level. The amount of water at this depth was estimated at 15 – 24%, and the hydraulic conductivity reached 20 m/d. The groundwater table depths obtained from the borehole data (~40 m b.g.l.) agree with the interpreted depths of magnetic resonance soundings. MRS studies have shown the hydraulic conductivity is almost 40% higher than the result from the pumping test (14.5 m/d), but still corresponds to the values noted in the literature (8.6-86 m/d). The gradual lengthening of the relaxation period (up to 600 ms) signifies the presence of large-diameter pores in the lower part of the aquifer. The lithological profile of wells located 250 m from the sounding point indicates that this result can be attributed to the separation of medium-grained sands which can be found 12 – 19 m below the surface. Research has shown that low-permeable rocks with very low effective water content (~ 1-2%) and a hydraulic conductivity of $6{\cdot}10^{-7}$ m/s (0.06 m/d) can be found in areas below aquifers as well as in the cover. These figures are reflected in the lithological profile of the wells (Fig. 2).

The signal received on the Maślice estate (western suburbs of Wrocław) is symptomatic of the presence of two aquifers. An aquifer with a water content of 20 – 40% and a hydraulic conductivity ranging from 10 – 16 m/d was observed up to 6 m below the surface. At depths between 6 and 15 m, both the water content and the hydraulic conductivity were very low, not exceeding 1% and 0.5 m/d, respectively. Further down they increased to 25% and 8 – 13 m/d (Table 1).

Table 1. Hydraulic conductivity of the aquifer obtained by MRS and pumping test (PT) and literature data* (LD)

Location	**Methods**	**k (m/d)**	**T (m^2/d)**
Mrozów	MRS	~20	259-785
	PT	14.5	102
	LD	8.6-86	9-611
Maślice (Wrocław)	MRS	8-13	14-285
	PT	5.9	51
	LD	0.86-8.6	22-662
Karczyce	MRS	65	66-233
	PT	81.1	3402
	LD	8.6-86	2466-9352
Bogdaszowice	MRS	~60	2074-15552
	PT	79.1	8691
	LD	8.6-86	2466-9352
Piława	MRS	0.2-8	1-86
	PT	0.4	7
	LD	0.06-0.86	15

*- Morris & Johnson, 1967; Pazdro & Kozerski, 1990; Kiełczawa et al., 1997; Mroczkowska, 1997

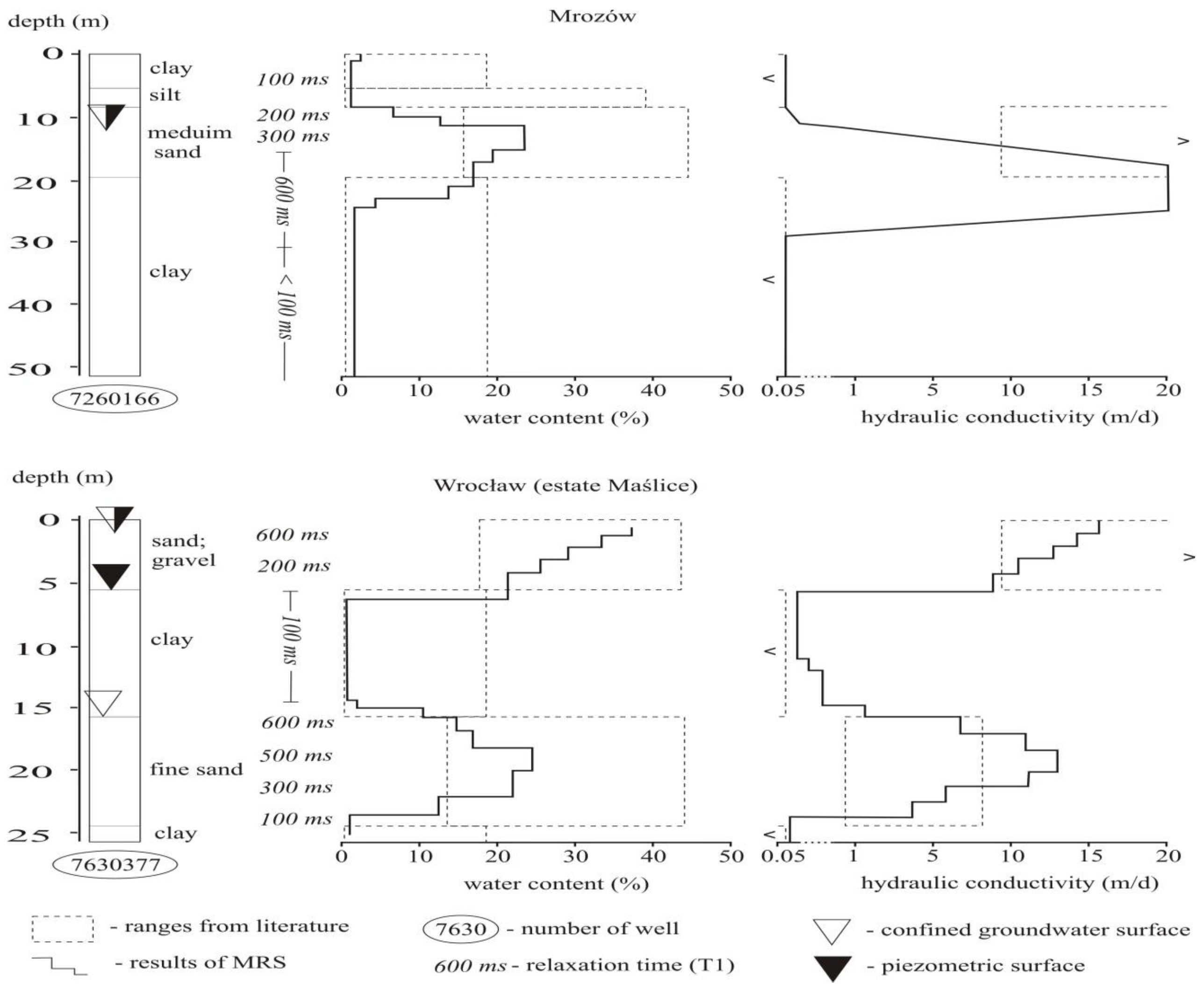

Figure 2. Water content and hydraulic conductivity estimates from MRS measurements in Mrozów and Maślice (Wrocław)

These results correspond with the layers of sand, gravel, loam and fine-grained sands observed during drilling (Fig. 2). In this case the MRS hydraulic conductivity is higher than the "k" results from the pumping test (MRS k = 8-13 m/d, pumping test k = 6 m/d).

The second test site was the Quaternary aquifer of Bogdaszowice – Radakowice. MRS results from the villages of Karczyce and Bogdaszowice (Fig. 3) are indicative of a relatively low or non-existent water content up to 30 – 33 m below the surface. In both cases, the water content does not exceed 10% and the hydraulic conductivity is lower than 1 m/d, which places the rocks under study in the low-permeable category. Only the sub-surface zone (up to 2 m) in Bogdaszowice signifies the presence of sediments with a water content reaching 20%. Both profiling tests implied the presence of semi-permeable and non-permeable rocks at depths of up to 30 m. A rapid increase in the hydraulic conductivity to over 20 m/d and a gradual increase in water content up to 22% in Bogdaszowice and 38% in Karczyce (permeable rocks) were noted at depths between 30 and 45 m. The MRS results were found to correspond with previous research and hydrogeological profiles of wells dug 200 – 250 m from the research area (Fig. 3, Table 1). The MRS results suggest the presence of a thicker aquifer, which can be identified with the Bogdaszowice buried valley. Water content and permeability figures (Fig. 3, solid black line) obtained through MRS correspond with the figures associated with particular sediments (Morris & Johnson, 1967). Taking into account the distance between sounding points and wells, as well as the variability of the geological structure in the region, it can be concluded that the estimated MRS figures reflect the occurrence of particular layers fairly accurately. In these cases, the MRS hydraulic conductivity is lower (60-65 m/d) than from pumping test (79-81 m/d).

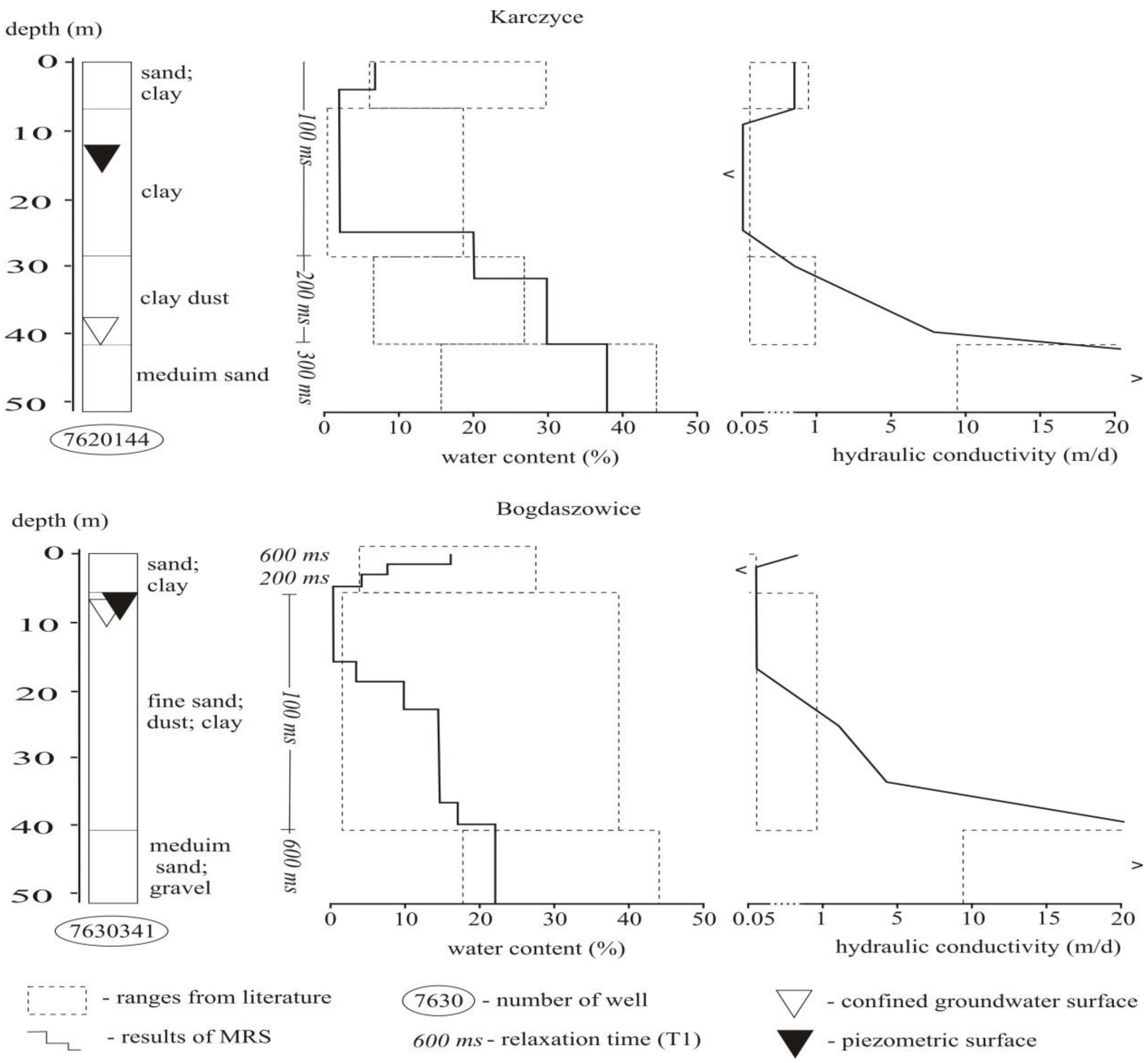

Figure 3. Water content and hydraulic conductivity estimates from MRS measurements in Karczyce and Bogdaszowice

The third series of tests incorporating two soundings was carried out in the Fore-Sudetic area of the Sowie Mts., which is composed of various metamorphic rocks - mostly migmatites, gneisses and fragments of amphiboles. In this area, two aquifers were identified: the upper layer is located in sub-surface rock waste and is characterised by a free or slightly confined water table. The lower part of the aquifer is confined and associated with deep water circulation within cracks, fractures, fissures and other forms of tectonic discontinuity in crystalline rocks. Magnetic resonance sounding was carried out approximately 2 km north of the village of Piława Górna. Both series of profiling are suggestive of either a very low water content of the weathering cover and rock massif or a complete lack of it. The weathering cover is approximately 4 metres thick, its water content does not exceed 6%, and the hydraulic conductivity equals $2 \cdot 10^{-6}$ m/s (0.17 m/d). This type of rock waste can therefore be classified as low-permeable. Transmissivity figures are low, at 10^{-6}-10^{-7} m^2/s. At depths greater than 4 metres, a cracked rock massif can be found, which shows a very low water content (2%), a hydraulic conductivity of 10^{-6} m/s (low-permeable rocks) and a transmissivity coefficient equalling 10^{-5} m^2/s. The hydraulic conductivity increases at depths of 40 metres (measurement no. 1) and 30 metres (measurement no. 2), where it reaches 10^{-4} -10^{-5} m/s. Research has shown a simultaneous increase in the transmissivity coefficient to 10^{-3} m^2/s. The increase in these parameters is associated with the presence of small local water inflow within the cracked rock massif, which is visible among others in the exposures of the nearby quarry. Considering the other test sites under study, where MRS readings were processed, there seems to be a marked correlation between the water content and hydraulic conductivity attributed to each site (Fig. 4) and the value of the pumping test hydraulic conductivity (0.4 m/d) is in the range of MRS result (0.2-8 m/d; Table 1).The data regarding the geological profile come from well no. 10/09, drilled either 200 metres to the east (measurement no.1) or 1000 metres to the north (measurement no. 2), depending on the sounding point. The repetitiveness of the results confirms the reliability of both soundings. The measurements, carried out in close proximity to each other (~1.2 km) and under similar hydrogeological conditions, differ slightly from each other, but are clearly suggestive of the important role of cracks and high-performance zones in water flow, which affects the zonal (heterogeneous) water content of crystalline massifs.

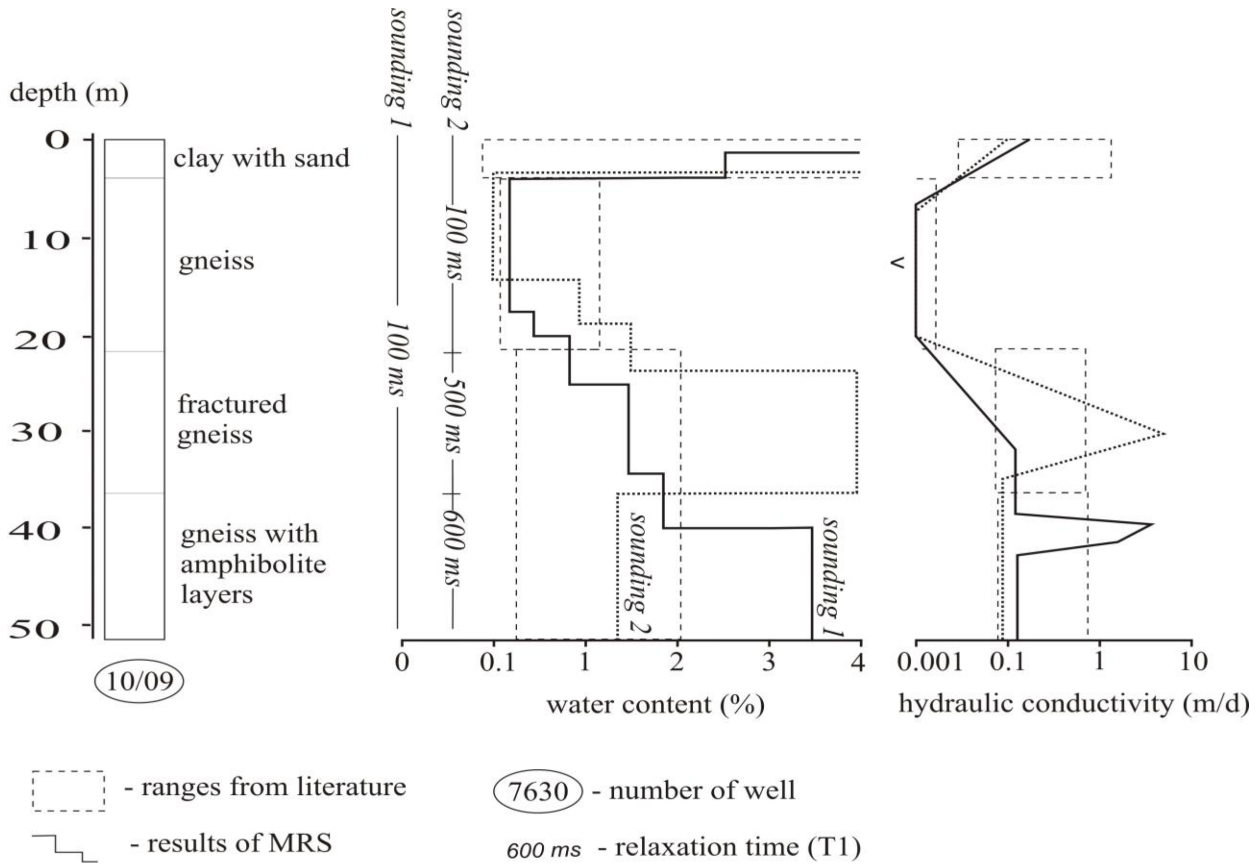

Figure 4. Water content and hydraulic conductivity estimates from MRS measurement in Piława

5. DISCUSSION

Results obtained in the three test sites indicate that MRS can be used in order to estimate the water content and thickness of particular layers as well as to determine the optimum depth of groundwater extraction. Researches confirm observations (Lubczyński & Roy, 2004, 2007), that the most important part of the research is choosing a location that meets the requirements of MRS measurements, that is when the quality of the received signal satisfies the following criteria:

- the curve of the MRS signal must be clearly separated from the noise curve
- is in decline for the curve shape the signal
- the maximum difference between frequencies cannot exceed 1-2 Hz.

Therefore, the study demonstrates that the minimum distance from infrastructure should be around 200-250 metres. Otherwise, as proved Lubczyński & Roy (2007) and Vouillamoz et al., (2007) the inversion of the MRS data into hydrogeological parameters have to be used with prudence, definitely not as fixed independent variables.

The sounding point should be characterised by a stable magnetic field of the Earth (+/- 20 nT), a low magnetic susceptibility (less than 10^{-2} SI units) and low electromagnetic noise (up to 1000 nV). These requirements mean that MRS cannot be performed in urbanised areas, places with volcanic rocks or areas where the water content of rocks is very low.

It has also demonstrated that in the case of water inflow areas, an electromagnetic noise level of 150 – 300 nV enables a relatively precise estimation of the depth and permeability of aquifers. Soundings conducted in south-western Poland have shown that owing to relatively high levels of electromagnetic noise, the use of magnetic resonance in hydrogeological research is limited to areas where the water content in rocks is at the very least moderate. In anhydrous or low-intensity water-bearing areas (where signals emitted by water particles are weak), the electromagnetic noise means that the defined hydrogeological parameters are highly susceptible to errors.

Hydrogeological characteristics along with the level of electromagnetic noise in the area under study have allowed for representative soundings to be carried out. Bearing in mind the distance between the MRS soundings and the wells, whose detailed lithological specifications between 200 and 500 metres below ground were included during research, as well as local variations in the geological structure, it can be concluded that the results correspond well with the occurrence of water-bearing layers and cracks in the orogen. Similar results obtained Mangisi (2004), who performed hydrogeological verification of MRS using data from the Maun area (Botswana) and Roy & Lubczyński (2003a), who tested the MRS in Southern Africa. Unfortunately, the MRS water detection ratio is 0.5% (Lachassange et al., 2005). This can cause considerable errors and, in the case of crystalline rocks where the water content is only a few percent, considerably limit the use of MRS. Nonetheless, a large increase of the hydraulic conductivity signifies the presence of high-performance flow zones (cracks, fractures, fissures or other forms of tectonic discontinuity) within which water inflow is possible. In addition, the MRS analysis suggests that in the case of high water content aquifers, hydraulic conductivity and transmissivity are lowers about 20%, while in low or medium water content aquifers MRS hydraulic conductivity value is about 40-80% higher. As in the case of the research (Vouillamoz et al., 2005) conducted without the knowledge of hydrogeological parameters which would enable the calibration of MRS results (Lachassange et al., 2005), which always happens in areas inadequately mapped, MRS enabled a successful location of water inflow layers.

Vouillamoz et al., (2005) showed that the depths and thicknesses of the saturated alterites are accurately described by the MRS results, and the mean differences with the borehole data are ±12% and ±17%, respectively. The storativity estimated from MRS data is not reliable. The transmissivity can be accurately estimated from MRS data after calibration with pumping test results. The mean difference between MRS and pumping test results is ±41%. Without calibrations process MRS method allows a low cost and non-invasive is able to estimate the hydraulic conductivity (or transmissivity), water content, thickness of the different layers, etc. of aquifers in localized favourable configurations (non-urban areas).

However, with additional data, e.g. archival geophysical, geological and hydrogeological research can be compared not only qualitatively. Lachassange et al., 2005 proved that the knowledge of one parameter, or even better two parameters, makes it possible to determine the second and third parameters, or the third parameter, with a much higher accuracy. Calibration of MRS parameters (specify the number of layers and their resistance), on the basis of existing data, when available, or on the experience of the team allows to get detailed information on the hydrogeological parameters of aquifer and the precise identification of the depth of the top of a confined aquifer, or the piezometric level in an unconfined aquifer.

Owing to the low number of places suitable for conducting soundings and the lack of detailed studies of hydrogeological parameters such as the hydraulic conductivity and water content, an analysis of the relationship between hydrogeological data and MRS has not yet been carried out.

6. CONCLUSION

MRS is a surface geophysical method and give the possibility of non-invasive detection of aquifers. MRS can be used for a reliable determination of the groundwater content and transmissivity of aquifer in the top 150 m. The magnetic resonance sounding (MRS) method was used to hydrogeological investigations in south-western Poland, in the Province of Lower Silesia. Three test sites were singled out, varying in geological structure and land use strategies. Two test sites were carried out in porous medium (Wroclaw city and surroundings). The third sounding was carried out in the Fore-Sudetic area of the Sowie Mts. representing fractured medium. Such areas include test sites where the sounding points were located near objects generating high levels of electromagnetic noise. The use of square loop shapes brings a significant improvement in noise reduction, albeit at the cost of shallower research depth (max. 25 m), but in the Lower Silesia very difficult to find a place with low electromagnetic noise and meet the criteria of measurement to obtain reliable results, not loaded with large errors.

The hydraulic conductivity determined from the pumping test was in the range from 0.4 m/d (fractured rocks) to 81.1 m/d (porous rocks). The hydraulic conductivity from the MRS was in the range 0.2 (fractured rocks) - 65 m/d (porous rocks). The transmissivity obtained from pumping test were respectively in the range 7-8691 m^2/d. The MRS transmissivity ranged between 1-86 m^2/d (fractured rocks) and 14-15552 m/d (porous rocks). The groundwater table depths obtained from the wells agree with the interpreted depths of magnetic resonance sounding.

MRS can be used in order to estimate the water content and thickness of particular layers as well as to determine the optimum depth of groundwater extraction, especially in the case of porous media with considerable groundwater resources. The results of soundings good correspond with the layers of sands, gravels, loams and fine-grained sands observed during drilling.

In anhydrous or low-intensity water-bearing areas, the electromagnetic noise means that the defined hydrogeological parameters are highly susceptible to errors. The biggest problems associated with magnetic resonance sounding concern in mountain areas (fractured medium in crystalline rocks). In most cases, in the Sudety Mts. can`t be made reliable sounding, even with noise reduction.

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