Applications of Ground Penetrating Radar (GPR) in Detection of Behavior of Groundwater Table Near Pumping Well*

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Abstract:

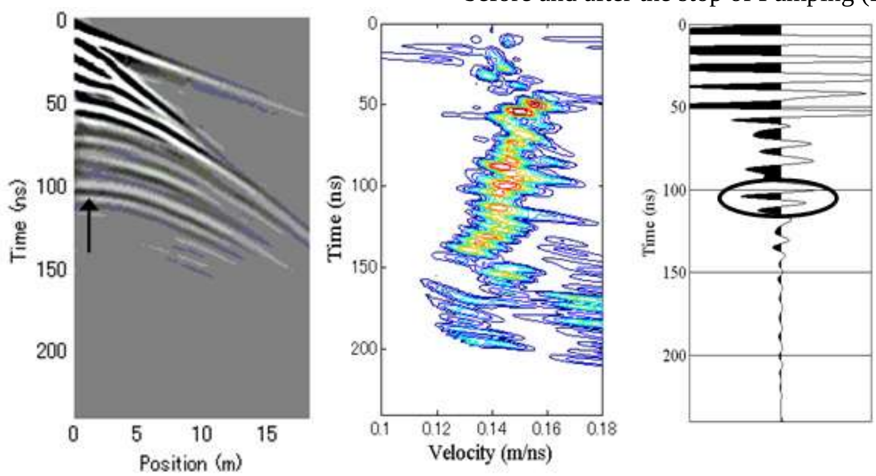
This study aimed to deep the understanding of the ability of ground penetrating radar in the groundwater studies, such as determine the behavior of groundwater table near pumping well using. The principles of GPR techniques and some of the previous works were reviewed.

The GPR survey repeated in the same profile near a pumping well using the same equipments and accessories but in different recovery times to monitor the movement of ground water table. Also the data processed for two another GPR profiles conducted at near time but with different distance from the pumping well.

The interpretations of the processed data reveal to the usefulness and high accuracy of GPR in the shallow groundwater surveys, the reflection of signals not reflect the real water table level but the top of capillary zone.

Introduction:

(Lu Qi, and Sato, 2005), determined the water table depth and the Hydraulic Properties of the aquifer depending on the separation of residual signal between the GPR profiles before and after the stop of Pumping (Figure 1).



(Figure 1): CMP profile, velocity spectrum, and trace analysis, (line N after Lu Qi, and Sato, 2005).

In the study of (Lu Qi, and Sato, 2005) CMP gathers acquired along survey line N when the well was in full-working condition (water level in the well was 8.25m). They Concluded:

1-The groundwater movement could be quantitatively estimated by comparing the two GPR data sets acquired under different conditions.

2-The residual trace shows distinguishable wavelet and makes it easy to locate the effective reflection points from the water level.

3-Combining quantitative information extracted from the GPR data with hydrogeological data, the estimation of hydraulic properties showed encouraging results.

(Kyosuke Onishi et. All, 2005) reported that the GPR surveys using CMP method has the potential to supply detailed groundwater information. This is because we can convert the spatially dense dielectric constant distribution, obtained by using the CMP method we describe, into a dense physical value distribution that is closely related to such groundwater properties as water saturation.

(Colin Mellor et. al., 2003) used the GPR survey to detect the effect of ground water solution cavities, North Carolina.

(Satoshi Ebihara, et. al., 2005) conduct an experimental study for monitoring the movement of water-level in Sand Tank by dipole-antenna array radar fixed in the subsurface.

(Mohammad H Makkawi, 2003), Use the integration of data of ground penetrating radar (GPR) with a kriging geostatistical procedure by conducting a case study in eastern Saudi Arabia and to evaluate its results under the condition of borehole deficiency. And he was recommended that it is a promising and economic approach to mapping shallow groundwater systems, determining aquifer boundaries and fate of contaminated groundwater.

(William P. Clement, 1997) used the GPR technique with another geophysical and geotechnical technique (Seismic and Electrical methods with CPT) to investigate the ground water surface.

(Bano, M., and Loeffler, O., 2005) studied the modeling GPR reflections from a water table. They are tried to answer the question (Why High GPR Frequencies don't Image the Water Table?), they simulate a water table (water level at 72 and 48 cm depth) by injecting water in a sand box that contains also some buried objects. The box was filled with fine calibrated sand having diameters between 0.3 and 0.5 mm. GPR profiles with 900 and 1200 MHz are performed in order to estimate the depth of the water level. This study also aimed to determine the effect of capillary fringe.

(Mangue, M., 2005) conducted a study to determine the near-surface water-content by using the comparison between surface GPR velocities and well GPR velocities. The multi-offset Ground Penetrating Radar (GPR) profiling confirmed with electrical conductivity measurements in this study. From the obtained data, total porosity was determinate and the monitoring of vertical transport from soil surface to the water table was performed each month.

(May, C. and Kinnicutt, P G., 2005) studied the advantages and pitfalls of time-lapse Ground Penetrating Radar in characterizing hydraulic properties. This study showed time-lapse GPR to be a potentially useful and inexpensive tool for estimating hydraulic properties.

(Pyke, K. A. and Daniels, J. J, 2005), conduct a study to estimate the GPR response to the LNAPL contamination in the vadose zone under fluctuating water table conditions. Results of the study indicate that under saturated conditions the main reflector of GPR energy is indicative of the capillary fringe and not the actual water table.

The reflection coefficient between gasoline saturated sand and the polyethylene tank is approximately 30% lower than that observed for the water saturated sand and polyethylene tank, indicating that the amplitude variation is directly related to the distribution of fluids at depth.

(Geosynce, 2000) used the GPR technique to detect the cavities under the foundations of industrial constructions in Baiji refineries area, Iraq. They recommended that the GPR technique is very efficient for the detection of solution cavities under the foundations of engineering structures.

(Mansor Nakhkash and Mohammad R. Mahmood_Zadeh, 2004) were used the ground penetrating techniques to detect the water leak from buried water pipe lines in Yazd city-Iran. The results confirm the usability of GPR for water leak detection.

(Yuji Takishita et al., 2004) were conduct a field study to measurements the ground water behavior in sandy soils using surface ground penetrating radar, the GPR measurements had a similar trend to water table behavior that measured by observation wells.

(Michaël Fuchs, et al., 2004) were used the integration between Seismic and GPR profiling to study the sedimentology of western Swiss lakes, they concluded that the GPR data give a good picture for the coarse grained sediments zone.

In order to conserve the groundwater environment near seashore region (Kyosuke Onishi, et al., 2004) tried to use GPR to detect the behavior of interface between the fresh and saline water, this research demonstrated the possibility of the conductivity mapping with GPR and the saline region detection.

(Yong Keun Hwang, et al., 2006) were done research to monitor the behavior of a chlorinated solvent which were released into an unconfined aquifer at Canadian Force Base Borden. Ground penetration radar profiling using 200 MHz antennas was performed before and after the release. The results of study demonstrated the ability of GPR to detect and monitor smaller volume DNAPL re-leases. It is also apparent that GPR profiling can be used to observe the long-term evolution of the DNAPL residual zones located in a natural groundwater flow regime.

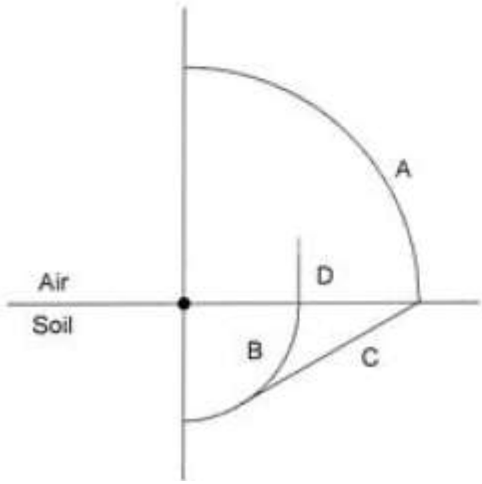
(McGlashan, et,a., 2006) used borehole radar in hydrological study to identify spatial variability in aquifer porosity. The groundwater flow velocity profile derived from the GPR data is in agreement with flow velocities measured at the site.

The study is a try aimed to deep the understanding of the ground penetrating radar systems and evaluate the usability of this system in the environmental studies. The training procedure contained the processing, analysis, and interpretations on two field data sets.

Theory of GPR:

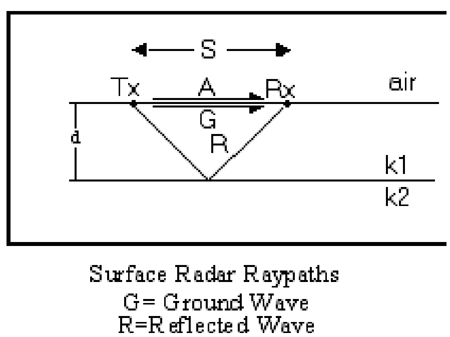
Ground penetrating radar is a geophysical measurement technique that has been extensively used to map the relatively shallow subsurface features at scales from kilometers to centimeters. The GPR technique is similar in principle to seismic, one antenna, the transmitter, radiates short pulses of high-frequency (MHz to GHz) electromagnetic waves, and the other antenna, the receiver, measures the signal from the transmitter as a function of time.

When the source antenna is placed on the surface, spherical waves are radiated both upward into the air and downward into the soil as indicated by wave fronts A and B. Because of the continuity requirements for the electromagnetic field at the soil surface, the propagating spherical air wave (A) gives rise to a lateral wave front (C) in the soil. Similarly, the spherical wave propagating in the soil gives rise to the ground wave (D). The ground wave amplitude is known to decrease strongly with distance above the soil surface, and therefore the ground wave is not presented as a wave front, (J. A. Huisman, et. al, 2003) (Figure 2).



(Figure 2): electromagnetic wave

Wave fronts around a dipole source on the soil surface. A and B are spherical waves in the air and soil, respectively. Wave C is the lateral or head wave in the soil, and D is the ground wave in the air. GPR resolution is determined by the period of the emitted pulse, which is controlled by the frequency bandwidth of the GPR system. Because impulse radar systems are designed to achieve bandwidths that are about equal to the center frequency, the resolution of GPR increases with increasing center frequency. Depth penetration of GPR measurements is strongly controlled by the soil electrical conductivity combined with the center frequency of the GPR system. In low-conductivity media, such as dry sand and gravel, low-frequency GPR systems (e.g., 50- or 100-MHz antennas) can achieve penetration up to several tens of meters, and high-frequency systems (e.g., 450- or 900-MHz antennas) achieve penetration of one to several meters. For silty sands and clays, depth penetration will be significantly less. The depth of penetration and resolution quality is decreasing as the percentage of clay increases in the soil (Xeidakis, G.S. et. al. 2004). Water has a high dielectric constant, so that radar waves travel more slowly in water-saturated ground (David L. et. all., 2005). It is important to realize that this high sensitivity to soil texture and electrical conductivity reduces the range of soils where GPR can successfully be applied (Figure 3).

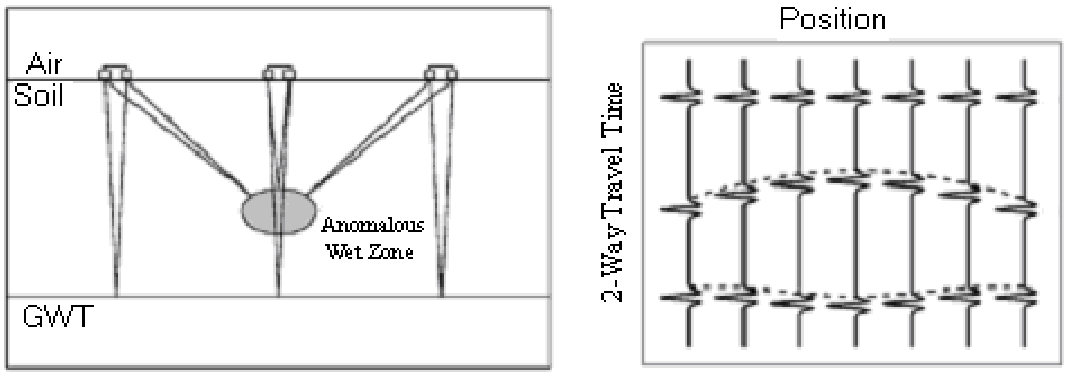


(Figure 3): Schematic illustrating air, ground wave, and reflected GPR energy travel paths. S is the separation distance between the transmitter (Tx) and receiver (Rx) after (Susan Hubbard, et. al.2001).

Data Acquire and Process :

Two types of methods of subsurface profiling by GPR. The first class contains the methods that use a single antenna separation. The second class contains the methods that require multiple measurements with different antenna separations.

The energy that GPR transmits into the soil will be (partly) reflected when contrasts in soil permittivity are encountered. (Figure 4a) shows an idealized GPR section measured with surface radar and a fixed antenna separation (single offset) over an anomaly (e.g., a water-filled pipe) having a different permittivity than the host material as shown in (Figure 4b).



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(Figure 4): (GPR) measurements with a fixed antenna separation over an anomalous wetter zone and a horizontal groundwater table (GWT) (J. A. Huisman, et. al, 2003).

A marks the air wave, B marks the point reflector, and C marks the reflection from the groundwater table (Davis and Annan, 2000). Since GPR emits waves in all directions, reflected energy is measured before the GPR is directly over it. The reflected events in the radar section trace out a hyperbola because the reflected energy of the GPR measurement directly above the anomaly has the shortest travel distance (time) and all other waves will have a larger distance to travel.

The zero time correction of arrival times is required to correct for the additional travel time at the beginning of each measurement, which is mainly due to the travel time in the cables of the radar system. A commonly used correction procedure consists of

1- Aligning the arrival times of the air wave to correct for drift in the zero time (e.g., caused by temperature changes affecting the radar system and the cables)
2- Estimating the average arrival time of the air wave.
3- Calculating the zero time correction from the average arrival time and the known antenna separation.

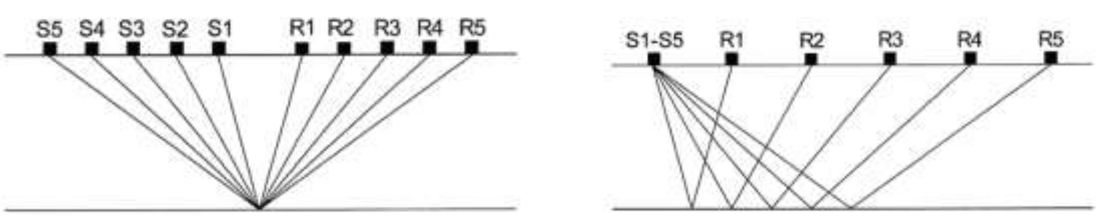
The accuracy of borehole GPR and single offset ground wave data depends on accurate zero time corrections, whereas the accuracy of multi-offset measurements does not depend strongly on accurate zero time corrections.

Single offset measurements cannot be used to determine water content from reflecting soil layers if no information about the depth of the reflector is available. In that case, one can use a multi-offset GPR acquisition geometry to determine soil water content from radar reflections.

Two commonly used multi-offset GPR acquisition geometries are called:

1-Common-Midpoint (CMP)
2-Wide Angle Reflection and Refraction (WARR) measurements.

In CMP acquisition, the distance between the antennas is increased stepwise while keeping a common midpoint (Figure 5a). In WARR acquisition, the distance between the antennas is increased stepwise with the transmitter at a fixed position (Figure 5b).



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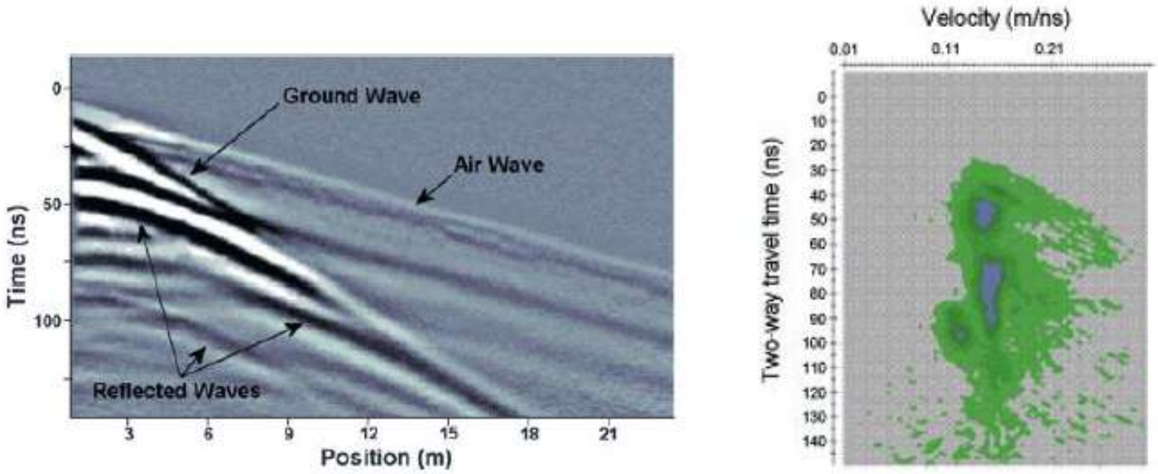
(Figure 5): multi-offset GPR acquisition geometries, (a) CMP method, (b) WARR method, S denotes the transmitter location and R denotes the receiver locations.

The ground wave can be identified as a wave with a linear move out starting from the origin of the x–t plot. In the slope equations, c is the electromagnetic velocity in air and x is the antenna separation (Sperl, 1999). A schematic outcome of a multi-offset GPR measurement is given in (Figure 6).



(Figure 6): the outcome of multi-offset CMP survey, The air wave, ground wave, and several reflected waves can clearly be recognized, in the right automatic velocity extraction (after (J. A. Huisman, et. al, 2003).

Most common GPR analysis software provides routines where the velocity can be determined by manually fitting hyperbola to the reflected waves in the multi-offset measurements. Multi-offset measurements also permit velocity determination from arrivals other than the reflected waves.

Semblance plot of the common-midpoint (CMP) measurement shown in the Figure above to illustrate automatic extraction of velocity vs. time. The semblance analysis does not result in very accurate velocity estimates. Although multi-offset measurements are widely used in GPR data processing for determining velocity profiles with depth. The ground wave is the part of the radiated energy that travels between the transmitter and receiver through the top of the soil. The ground wave is detected by the GPR receiver, even in the absence of clearly reflecting soil. The evanescent character of the ground wave measured by the GPR receiver antenna at the soil surface requires that both the transmitter and the receiver be placed close to the soil surface.

The ground wave can easily be recognized on data collected using a multi-offset GPR acquisition geometry, by the observed linear relationship between antenna separation and ground wave travel times, which starts at the origin of the multi-offset measurement set.

The slope of the ground wave in a multi-offset measurement is directly related to the ground wave velocity.

Estimation of soil water content using multi-offset GPR measurements is cumbersome and time-consuming, as was mentioned before. The ground wave velocity can also be determined from a single offset GPR measurement, provided that the approximate arrival time of the ground wave is known from a multi-offset GPR measurement.

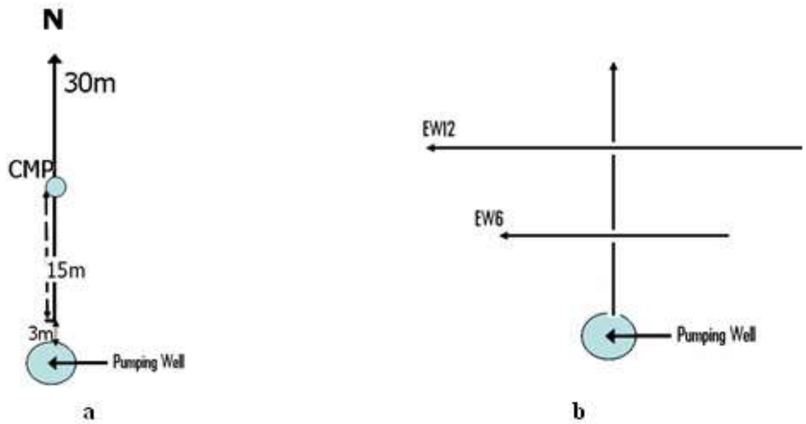
(Susan Hubbard, et. al.2001) Studied Near-Subsurface Water Content using Surface GPR Ground Wave Information. They concluded that the GPR ground wave travel time data was shown to yield high-resolution information about volumetric content for the very near surface, especially, when use the comparison between the different methods of survey.

Field experiments:

The profiles surveyed using RAMAC GPR system, The Common offset Survey method was done by the antenna of 250 MHz frequency, the interval of data acquire = 0.05m, and antenna offset = 0.36m. The frequency of antenna used for CMP survey is 100 MHz, and the interval = 0.2m.

The survey done to reprocesses the data of behavior of water table in selected area near a pumping well to monitor the recovery of ground water after the shutdown of pumping. The data reprocessed from the study of (Lu, and Sato, 2005).

In this case the survey repeated in the same Profile (N) (location) using the same equipments and accessories but in different recovery times to monitor the movement of ground water table. (Figure 7a). Also the data processed for two GPR profiles conducted at near time but with different distance from the pumping well (Figure 7b).



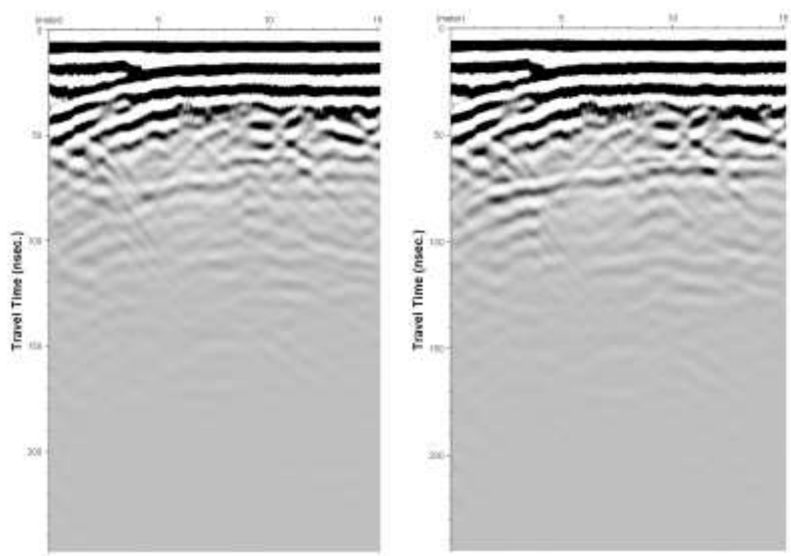
(Figure 7) :the surveyed lines area for 2nd studied case.

Data analysis and Discussion:

RADPRO/GPR software used for the data processing in this study. This investigation was done to determine the depth and behavior of water table near a pumping well with the recovery after the stop of pumping in the well. The profiles along three lines discussed in this case. Along the line (N) (Figure 7a) the survey repeated in two times using the same equipments and accessories but in different recovery times to monitor the movement of ground water table.

The adjusted zero time and DC filtered GPR images revealed to changes in the reflections between the images of different recovery in the range of depth about 3.5-4.4 meters (Figure 8).

In the image on the right at 5 Oct. the water table more raised and more clear than that at 4 Oct. because the effect the recovery of water after the stop of Pumping.



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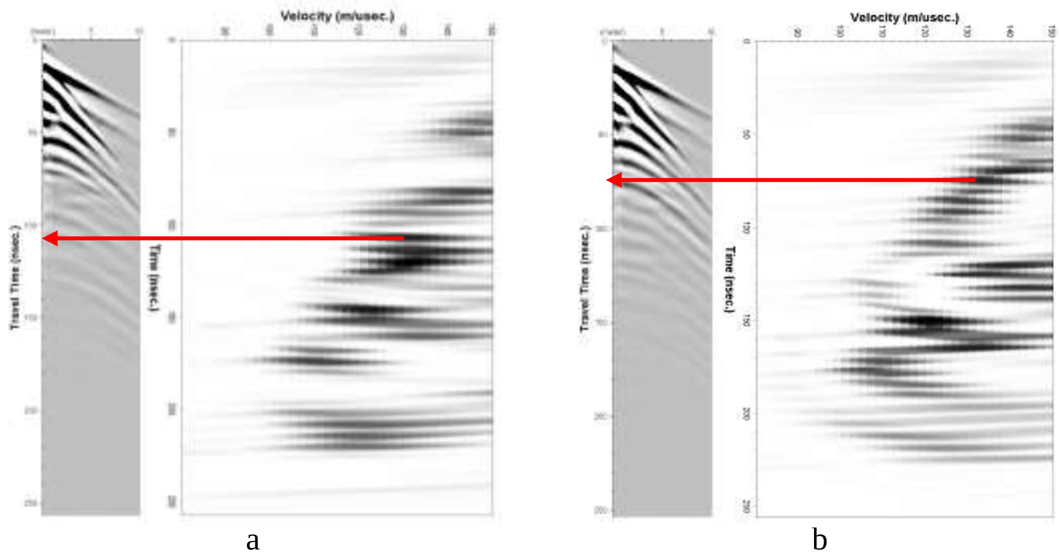
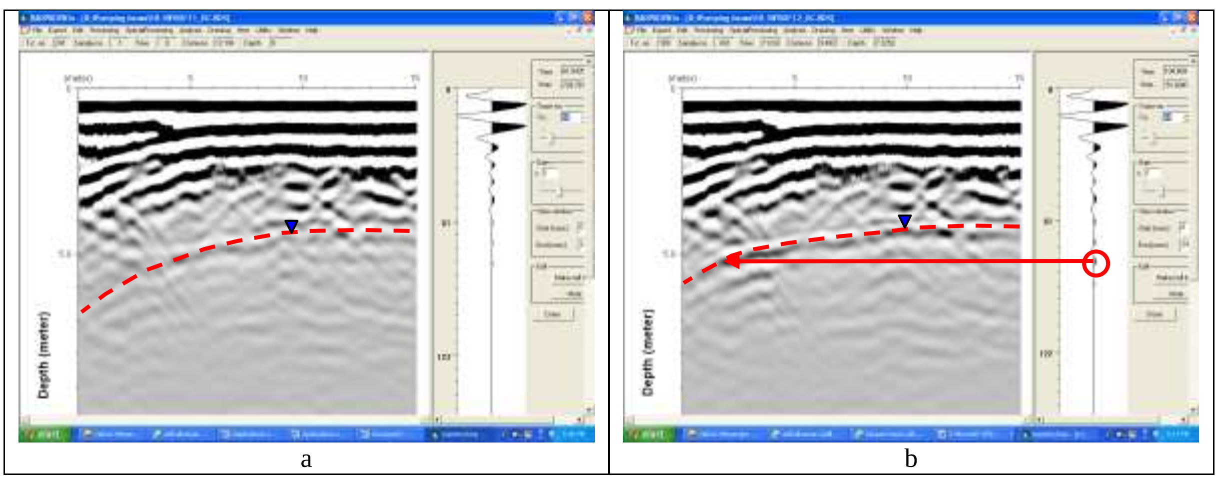
(Figure 8): The adjusted zero time and DC filtered Common off-set GPR images of profile (N), (a) at 17:00 of 4 Oct (b) after more recovery at 9:40 of 5 Oct.

The CMP survey conducted for the same line profile at different times (14:40 of 4 Oct. and 11:05 of 5 Oct), The Velocity Spectrum analysis of these profiles also confirm the idea of rising of water table with recovery time (Figure 9). The reflection of high energy from the water table in the two CMP profiles reflected at velocity of 130 m/μsec, this velocity used in calculation of depth in the common off-set profiles below to determine the depth of water table.



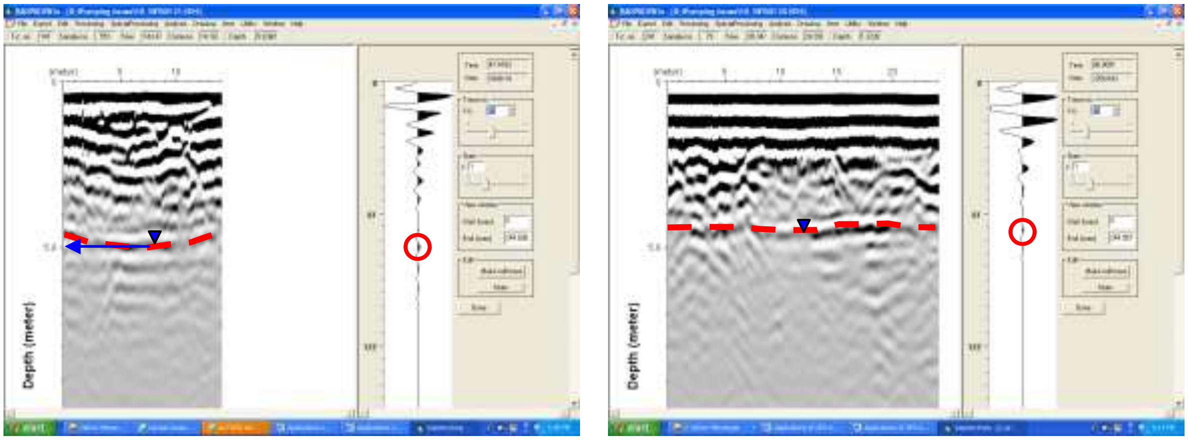
(Figure 9): The CMP survey for the same line (a) CMP profile image and velocity spectrum at 14:40 of 4 Oct. (b) profile image and velocity spectrum at 11:5 of 5 Oct.

The data of selected traces reveal to high reflection from the suggested ground water table that marked by dashed line (Figure 10). That reveal to rising of the water table about 0.9m, from the depth 6.7m at 17:00 of 4 Oct, to the depth (5.8m) at 9:40 of 5 Oct. (form the depth 6.7m in (a) to depth 5.8m). The curvature of the dashed line, represent the curvature of cone of depression around the pumping well, the curvature in the early drawdown (a) more than the curvature of lately drawdown (b).



(Figure 10): Common off-set GPR images of profile (N) with selected traces, the circle around the reflection from water table (a) at 17:00 of 4 Oct (b) after more recovery at 9:40 of 5 Oct.

The survey applied along the two lines in (Figure 7b), the distances are 6m and 12m between the pumping well and the lines EW6 and EW12 respectively, the survey were done in the two lines in near time of recovery for the comparison of water table in the two locations (Figure 11). The time shift and DC filter were done on the two profiles, the velocity 130 m/µsec applied to determine the depth of water table. In the left the water table appear as concave line because the effect of cone of depression (the mid point of the line near to the well more than the ends, the mid point of water table depth in this line about 4.9m, while the depth in the far line EW12 about 4.5m, the 0.4 m different in depth because the effect of gradient of cone of depression, the water table in EW12 line appear low concave because the radius of effect more than the radius in another line.



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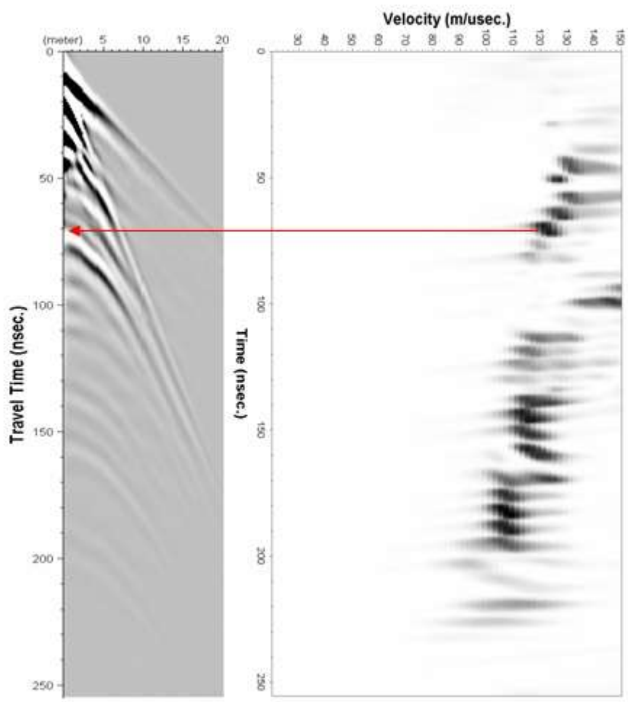
(Figure 11): (a) profile EW6 (b) profile EW12, the dashed lines represent the water table, and red circles surrounded the traces of reflections from water table in the two profiles.

The GPR survey repeated for more details in the same place (Figure 7a) but with longer profiles in 5th – 8th Oct. 2004, the survey done with three stages, the first when the near pumping well in full production, the second in half production, and the third no production. The CMP profile conducted on the line N in the Full production stage, the DC- filtered and time shifted profile in (Figure 12a). The reflection of high energy of groundwater table appear in the two way travel time 72 nsec, the velocity spectrum analysis of the profile reveal a high energy reflection in this time with velocity 121.6m/µsec (Figure 12b).



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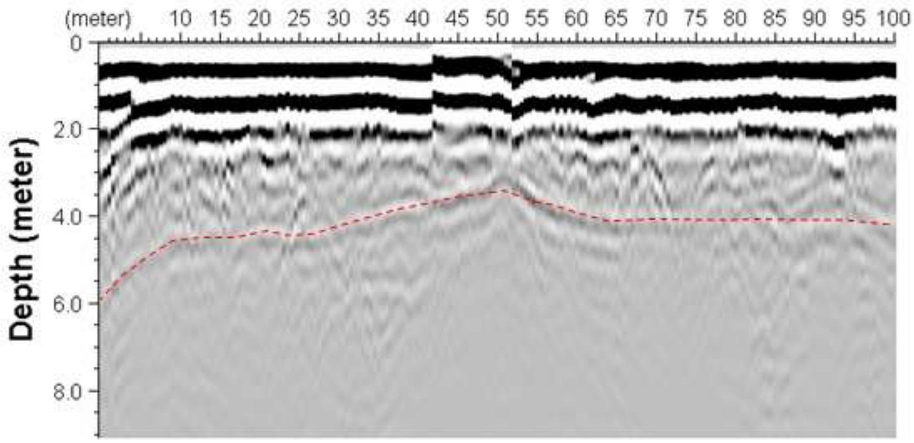
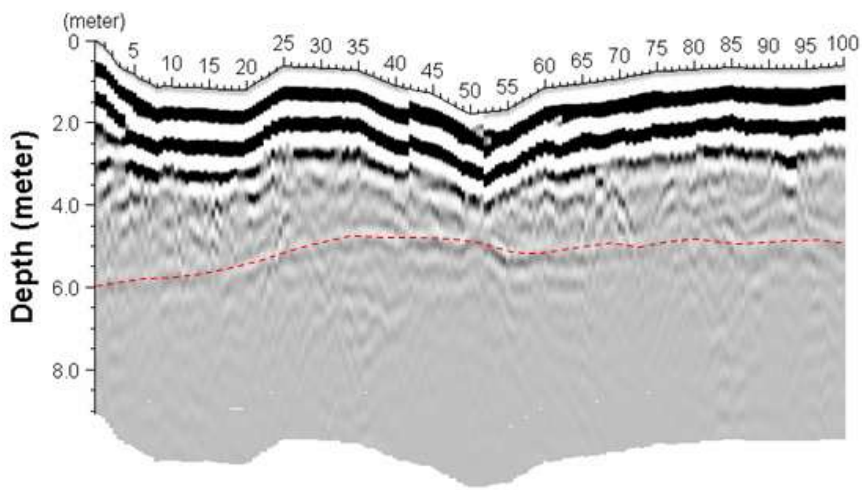
(Figure 12): CMP profile on the line N in conducted in full production stage on 5 Oct. 2004, (a) CMP GPR profile Image, (b) Velocity spectrum analysis of the profile.

The determine velocity applied in the next processing on the common off-set profile which conducted in the same pumping stage (4th Oct. 2006) and location, to determine the depth of targeted water table. The DC- filtered and time shifted common off-set profile in (Figure 13), the dashed line represents the water table reflections.



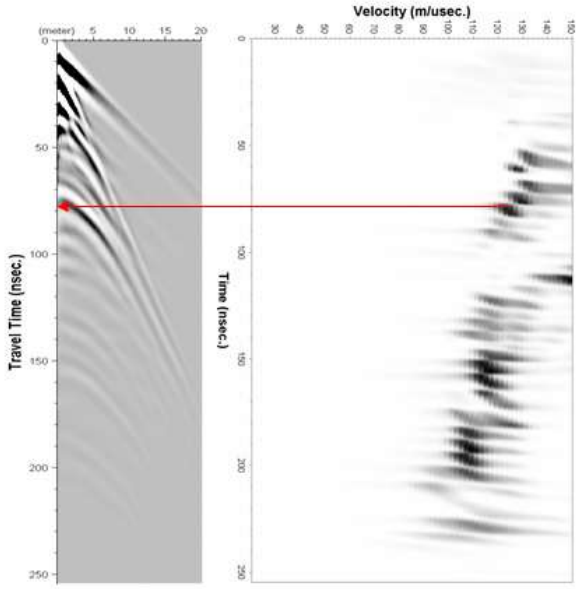
(Figure 13): DC-filtered and time shifted common off-set profile in line N on the Full production Stage (4 Oct. 2004).

The topographic corrections applied on the profile to more explain of the behavior of ground water table (Figure 14). In this profile the ground water table appears on the depth of about 6 meters, also the effect of cone of depression appear, in this figure its smoother than that in figure 13, but some time it is undulated from location to another, the reflection of signals not from the real water table but from the top of capillary zone, the capillary zone effected by the soil texture, the subsurface structure caused a crush of soil texture and the grains of soil be finer than non-effected soil, so, the capillary raised in the fine grains soil and the undulation related with undulation of the top of capillary zone.



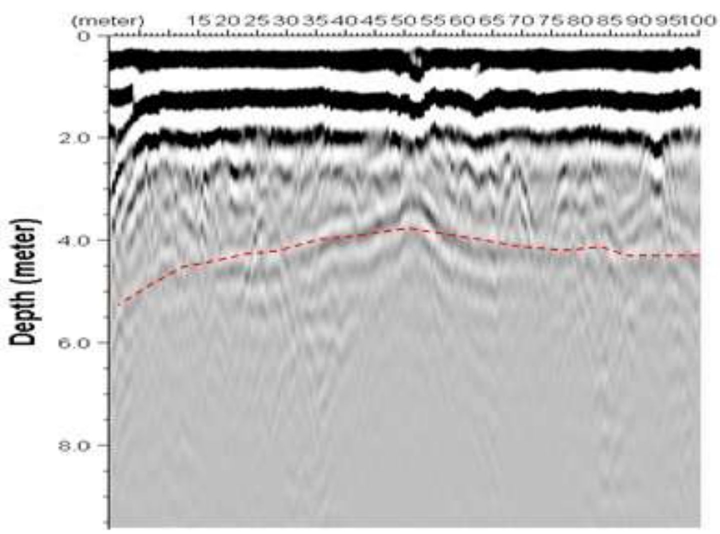
(Figure 14): DC-filtered and time shifted common off-set profile in line N on the Full production Stage (4 Oct. 2004) after topographic corrections.

The CMP profile of no production stage on 8 Oct. 2006 in the same line (N) (Figure 15a), it was DC- Filtered and time shifted. The reflection of ground water table appear when the travel time about 77nsec in this profile, the velocity spectrum of the profile analyzed and compared with the same profile, the reflection of high energy in this travel time reveal to velocity about 128.6m/µsec (Figure 15b).



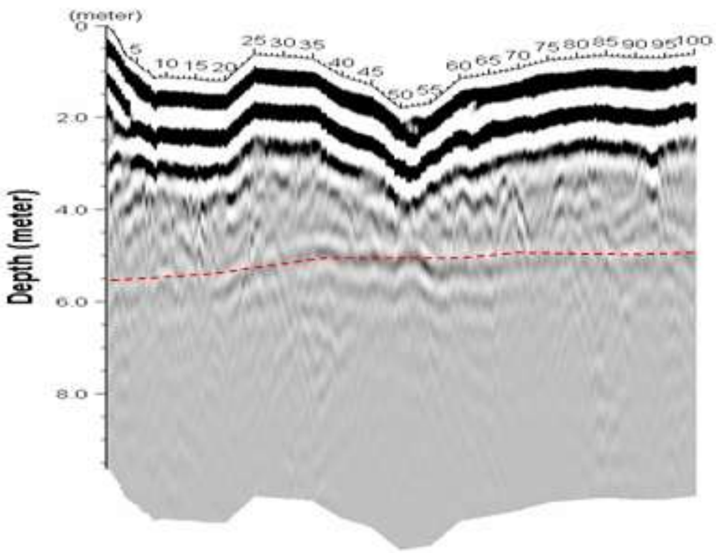
(Figure 15): CMP profile on the line N in conducted in no production stage on 8 Oct. 2004, (a) CMP GPR profile Image, (b) Velocity spectrum analysis of the profile.

The determine velocity applied in the next processing on the common off-set profile which conducted in the same stage (8th Oct. 2006) and location to determine the depth of targeted water table. The DC-filtered and time shifted common off-set profile in (Figure16), the dashed line represents the water table reflections.



(Figure16): DC-filtered and time shifted common off-set profile in line N on the no production Stage (8 Oct. 2004).

The topographic corrections applied on the profile to more explain of the behavior of ground water table (Figure 17). In this profile the ground water table appears on the depth of about 5.65 meters, also the effect of residual cone of depression appear, the water table in this figure smoother than that in figure 15, but some time it is undulated from location to another, the undulation also related with the top of capillary zone as in figure 14.



(Figure 17): DC-filtered and time shifted common off-set profile in line N on the no production Stage (8 Oct. 2004) after topographic corrections.

The different in the depth of water table about 0.35 m because the effect of recovery of groundwater table after the shutdown of the pump. The oscillation of groundwater surface in the profiles of the two stages (full production and no production) because the effect of subsurface structures, such as micro faults and joints that effect to the capillary zone, and the marked water table not the real water table, but the top of the capillary zone (or the geophysical water table).

Summery and Conclusions:

GPR is a relatively modern technique; it is used widely in the last decades to explore the shallow subsurface phenomenon. One of the most important promise uses of GPR in the future is the environmental applications.

In this case study the investigation was done to determine the depth and behavior of water table near a pumping well with the recovery after the stop of pumping in the well. The profiles along three lines discussed in this study. Along one of the lines the survey repeated in two times using the same equipments and accessories but in different recovery times to monitor the movement of ground water table.

The adjusted zero time, DC filter, velocity spectrum analysis, and automatic gain control of GPR images revealed to changes in the reflections between the images of different recovery in the range of depth about 4.5-6.7 meters. These changes interpreted as a result of ground water table fluctuation.

The survey applied along other two lines in different distances between the pumping well and the two lines, the survey were done in near time of recovery for the comparison of water table in the two profiles. The comparison between the two profiles reflect the different effect of the cone of depression on the shape of water table, the water table in the near profile appear as concave line because the effect of cone of depression, the mid point of water table depth in this line about 3.2m while the depth in the far line about 2.9m, the 0.3 m different in depth because the effect of gradient of cone of depression, the water table in far line appear low concave because the radius of effect more than the radius in another line.

The survey repeated in the same location of first line after 3 years but the profiles longer than the first survey for more details information about the behavior of ground water table. The processing of CMP and common off-set profiles reveal to rising from the depth 6 meters during the full production stage to depth 5.65 meters in the stage of no production that confirm the ability of GPR technique for such studies.

The results of this research encouraged to use the GPR techniques for these types of environmental studies and to do more applications on another types of shallow subsurface environmental problems in depth zone about (10m) such as; detection of subsurface solution cavities, detection of leakage from subsurface water pipes, soil contamination, evaluation of ground water recharge, estimation of hydraulic properties of groundwater aquifers, evaluation of the grouting of subsurface cavities.

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استخدام رادار الاختراق الأرضي(GPR) للتنبؤ بسلوك منسوب المياه الجوفية قرب احد الابار المائية

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الملخص:

تهدف هذه الدراسة الى تعميق فهم قدرة رادار الاختراق الارضي(GPR) في دراسات اللمياه الجوفية مثل تحديد سلوك سطح المياه الجوفية قرب بئر الضخ. وقد تمت مراجعة مبادئ عمل تقنية الرادار الارضي مع مراجعة لبعض الأعمال السابقة في نفس المجال.

تم اعادة مسح نفس المسار باستخدام نفس الجهاز ونفس الهوائيات في أوقات مختلفة بعد بدئ عودة ارتفاع منسوب المياه بعد توقف الضخ. كما تم اجراء المسح لمسارين متوازيين على مسافات مختلفة من البئر في اوقات متقاربة.

بينت نتائج المعالجات التي تم إجراؤها على البيانات الرادارية إمكانية استخدام هذه التقنية وبدقة عالية للتحري عن سلوك منسوب المياه الجوفية في الخزانات الضحلة. كما لوحظ ان الإشارات المنعكسة من منسوب المياه الجوفية لا تمثل المنسوب الحقيقي بل تمثل الجزء العلوي لنطاق الخاصية الشعرية.