Δελτίο της Ελληνικής Γεωλογικής Εταιρίας τομ. XXXX, 2007
Πρακτικά 11ου Διεθνούς Συνεδρίου, Αθήνα, Μάιος 2007

Bulletin of the Geological Society of Greece vol. XXXX, 2007
Proceedings of the 11th International Congress, Athens, May, 2007

PRELIMINARY RESULTS OF GROUNDWATER RECHARGE EXPERIMENTS IN LARISA PREFECTURE

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Abstract

Thessaly is the most important agricultural region in Greece and their economic development is influenced by the availability of water resources. During the last decades the overexploitation has lowered the groundwater level. The paper presents the results of artificial recharge in the aquifer system of Larisa prefecture through injection borehole and trench. The experiments took place during the period March – April 2006. The field experiments provided useful guidance on the planning of pilot tests, data monitoring and analysis, which can also be applied to other regions with similar hydrogeological conditions. Finally, this work confirms that groundwater recharge using the wintertime torrential flows is an environmentally acceptable solution, as part of an integrated water resources management strategy.
Key words: *Groundwater recharge, field experiment, Thessaly.*

Περίληψη

Η Θεσσαλία είναι μια από τις πιο σημαντικές περιοχές της Ελλάδας όσον αφορά τη γεωργική παραγωγή. Για το λόγο αυτό η ανάπτυξη της περιοχής βασίζεται στη διαθεσιμότητα υδατικών πόρων. Τις τελευταίες δεκαετίες όμως καταγράφηκε σημαντική πτώση στάθμης του υπόγειου νερού, λόγω υπερεκμετάλλευσης. Στην εργασία αυτή παρουσιάζονται τα πρόδρομα αποτελέσματα ενός πειράματος τεχνητού εμπλουτισμού στην ευρύτερη περιοχή του νομού Λάρισας, τόσο με την εισπίεση νερού σε γεώτρηση, όσο και με τη χρησιμοποίηση ανοικτής τάφρου. Τα πειράματα πραγματοποιήθηκαν την περίοδο Μαρτίου-Απριλίου 2006. Τα πειράματα στο πεδίο έδωσαν χρήσιμα συμπεράσματα όσον αφορά το σχεδιασμό και την υλοποίηση αντίστοιχων μεθόδων σε μεγαλύτερη κλίμακα σε περιοχές με παρόμοιες υδρογεωλογικές συνθήκες. Τέλος, με βάση τα αποτελέσματα επιβεβαιώνεται πως ο τεχνητός εμπλουτισμός με τη χρησιμοποίηση των χειμερινών απορροών, αποτελεί μια περιβαλλοντικά αποδεκτή λύση ενταγμένη σε μια ολοκληρωμένη στρατηγική διαχείρισης των υδατικών πόρων σε μια περιοχή.
Λέξεις κλειδιά: *Τεχνητός εμπλουτισμός, πειράματα, Θεσσαλία.*

1. Introduction

Thessaly is dependent on groundwater resources for its water supply. It is the most important agricultural region in Greece. The land in the northeastern part of Thessaly is mainly used for the cultivation of cotton, cereals, tomatoes (Fig. 1). The mean annual rainfall of the area is 413 mm (station Larisa, period 1960-2005) and the average annual temperature is 15.1 °C (station Larisa, period 1970-2005). The area is characterized by unhomogeneous distribution of rainfalls and water resources. Water requirements for agricultural are high during the dry period (April-October) when the water availability is low.

The economic development of this area is influenced by the availability of water resources. The main source of irrigation water supply in northeastern part of Thessaly is groundwater, occurring in Quaternary deposits. The intense and extensive cultivation has led to a remarkable water demand increase, which is covered by the overexploitation of groundwater resources. In the last decades, groundwater extraction for irrigation use, has caused a significant decline in the piezometric level. Conservation of surface runoff is considered important to improve the groundwater potential and to offset the adverse effects of groundwater mining, which have taken place in many parts of Thessaly.

The artificial recharge of the aquifers could present an attractive solution to some problems, e.g. quantity and quality of groundwater (Buchn 1964, Bize *et al.* 1992, Bouwer 1996, Giao *et al.* 1998). Based on previous studies, it is concluded that groundwater recharge is an environmentally acceptable solution, as part of an integrated water resources plan, in order to improve the quality and quantity of groundwater (Peters 1985, Hionidi *et al.* 2001, Murray *et al.* 2002). Experimental investigations on artificial groundwater recharge via deep boreholes in Greece were undertaken by Fleet *et al.* (1995), Vafiadis *et al.* (1996), Koumantakis *et al.* (1999), Diamantis *et al.* (1999), Poulovasilis *et al.* (2002), Stavropoulos *et al.* (2005), Voudouris *et al.* (2006). The results showed that the injected fresh water stored in the aquifer could be recovered in the dry period when the water availability is low (Soulios 2004).

This paper deals with the results of groundwater recharge field experiments in northeastern part of Thessaly, prefecture of Larissa, via borehole and trench, during 2006. Firstly, the results of the hydrogeological study, including development of aquifers, water level measurements, hydraulic parameters and groundwater quality are presented.

2. Geological and Hydrogeological settings

2.1. Geology

The Chalki - Platykampos area in the prefecture of Larisa is a lowland area which is covered by quaternary deposits. The study area is covered by a geological map at a scale of 1:50,000; this map was surveyed by the Institute of Geological and Mineral Researches (IGME, Katsikatsos, Vidakis, Migiros, 1981). According to this map, in a range of 10-15 km away from the study area (Fig.1) there is no surface presence of other geological formations, but only alluvial and Plio-Pleistocene fluvial deposits.

In the southern part of Chalki, close to the Larisa- Athens National Highway a geological formation outcrops, which consists of mica schist, gneiss schist with layers of white, Jurassic age, marbles. This formation constitutes a part of early upper Cretaceous nappe which is visible in the north-eastern part of the study area, close to the Ossa Mountain. This nappe seems to be the bedrock of the study area.

The stratigraphic sequence of this area consists of:

- Early upper Cretaceous nappe
- Plio-Pleistocene fluvial deposits

- Quaternary deposits, as we can see in the geological profile of borehole B1 (Fig. 2) including:
  - Terrestrial deposits
  - Lacustrine deposits; the Lake Karla covered in the past bigger area than during the historic years
  - Deeper terrestrial deposits with transition characteristics probably to the Plio-Pleistocene fluvial formations.

Based on drilling data of the injection borehole (Fig. 2) the Quaternary deposits of the study area consist of alternations fine and coarse grain size materials.

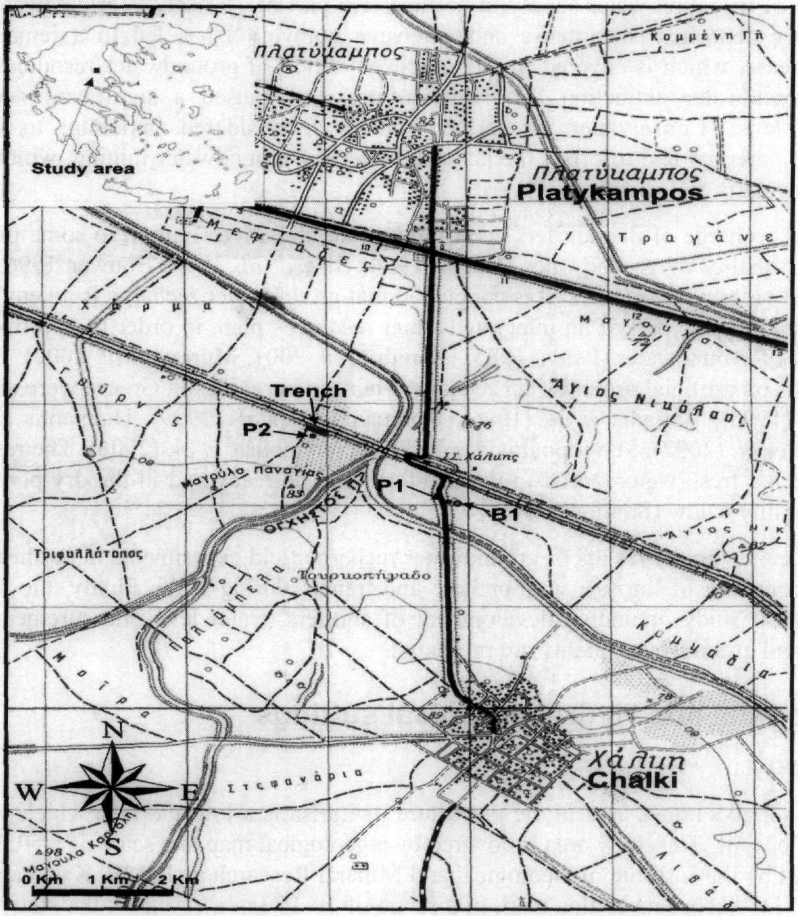

Figure 1 – Topographic map of the study area

2.2. Hydrogeology

The terrestrial facies of the Quaternary deposits form a multiple aquifer system, which is at least 400 m thick. This aquifer system is the main source that covers the water demands, by numerous deep boreholes.

The water level within these deposits was at an average depth of about 20-30 m below ground surface (b.g.s.) in the northern part, whereas in the south western part 140-170 m b.g.s.

The hydrograph of one representative borehole, drilled in alluvial aquifer of the study area is presented in Figure 3, showing the decline of the groundwater level (~50 m) during 1972-2003.

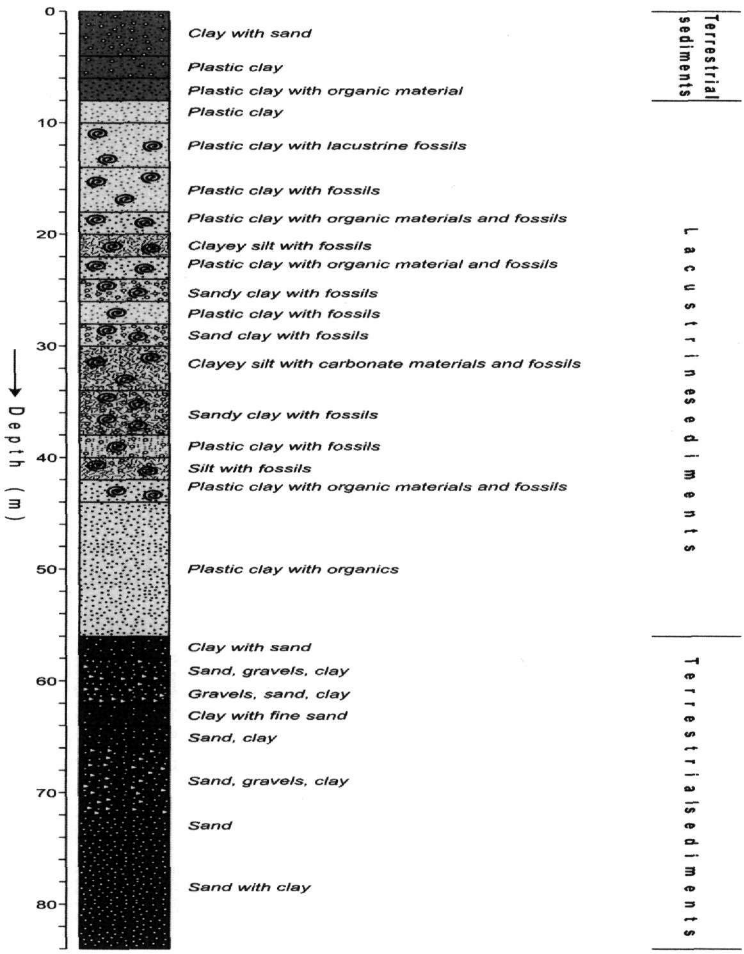

Figure 2 – Geological profile of borehole B1

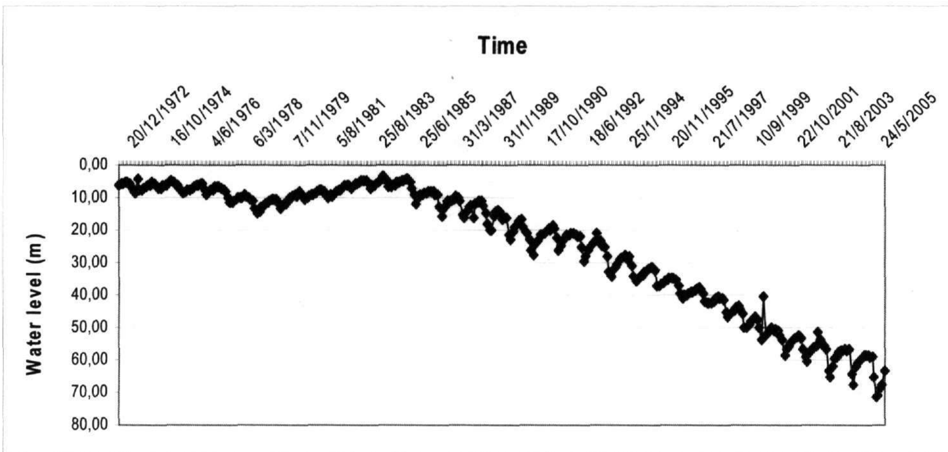

Figure 3 – Hydrograph of groundwater table fluctuations (m from the ground surface) in a representative borehole of the study area during the period 1972-2003

3. Artificial recharge tests

3.1. Drilling and pumping test

One new borehole was drilled (B1), 3 km North from the village of Chalki. The location is shown in Fig. 1. The selection of the location was made by using criteria like availability of land, high permeability, water availability to recharge, etc. After borehole had been drilled, pumping test (constant discharge 24-h) was carried out, in order to estimate the hydraulic parameters. The pumped discharge of the borehole was measured to be 26 m^3/h. The groundwater level was encountered at an average depth of 19.5 m below the ground surface. Furthermore, one piezometer (P1) was drilled at a short distance (~18 m) from the borehole B1.

Transmissivity (T), Storativity (S) and hydraulic conductivity (k) were calculated using the Cooper-Jacob method (Jacob, 1946, Batu, 1998). The mean coefficient of Transmissivity is 3.1×10^{-3} m^2/s and the hydraulic conductivity $k=2.6 \times 10^{-5}$ m/s. Storage coefficient is 10^{-2}.

3.2. Recharge water injection system

Water from another pumping borehole (at distance of 500 m), without any treatment, was used during the artificial recharge experiment in the borehole B1 (Fig. 4). Measurements of groundwater level were made in the piezometer of the recharge borehole and the piezometer P1 at distance of 17.85 m from the borehole B1.

The quality of the recharge and existing water is shown in Table 1. The differences could be associatedwith the different depths of boreholes. The Mg-HCO_3 is the dominant water type.

The duration of the recharge experiment was relatively short (7 days). The recharge flow rate was initially 20 m^3/h for 4 days and then it was increased at 30 m^3/h until the end of the experiment. The total volume of recharge water in the boreholes was 4,080 m^3. After the end of the recharge experiment, water level measurements were taken place for another 8 days.

Figure 4 –Water recharge injection system

3.3. Artificial recharge through trench

The trench is located close to the railway and has a length of 110 m (Fig. 5). Water from the neighbouring torrent, without any treatment, was used. Measurements of groundwater level were made in the piezometer at a distance of 15 m from the trench (Fig. 6). The quality of the recharge water is shown in Table 1.

Table 1- Chemical analyses (mg/L) of water

	pH	E.C. (µS/cm)	Ca	Mg	Na	K	HCO_3	Cl	SO_4	NO_3
Existing water in borehole B1	7.80	809	19	68.7	55	1.4	326	14	112	4.4
Recharge water	7.86	632	16.8	32.4	72	1.3	241	12	86	17.6
Recharge water in trench	7.74	1245	70	96.1	101	3.5	361	93	219	91.1

Figure 5 –Water recharge system through trench

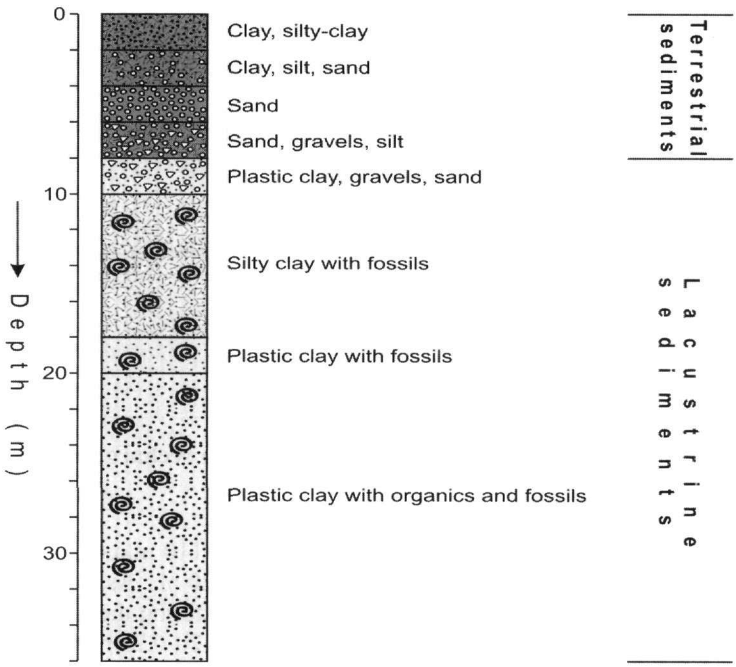

Figure 6 –Geological profile of piezometer P2

The duration of the recharge experiment was 7 days. The recharge flow rate was initially 45 m^3/h for 6 days and the last day it was 60 m^3/h until the end of the experiment. The total volume of recharge water in the trench was 7,920 m^3. Water level measurements were taken place during the experiment and for 10 days after the end of the experiment.

4. Results

4.1. Water recharge via borehole

The rise of the groundwater level at the end of the experiment in the borehole B1 ranges between 3.5 m in piezometer P1 and 5.5 m in borehole B1, assuming that the water level due to natural recharge was negligible. The groundwater level rise was decreasing with the distance from recharge borehole. The overall results of the groundwater recharge experiments are presented in Table 2.

Figure 7 shows the fluctuation of the water level in the recharge borehole B1 and in the piezometer P1 at distance 17.85 m, during the experiment. Figure 8 shows the fluctuation of the water level in the recharge borehole B1 and in the piezometer P1 for the time after the end of the experiment.

Transmissivity (T) was calculated to be 3.4×10^{-3} m^2/s, based on the analysis of the data of the recharge. Specific capacity (Q/s) is defined as the ratio of discharge (Q) to drawdown (s) at the pumping borehole for a given time.

The specific capacity (Q/s) was estimated to be 3.8 $m^3/h.m$ during the pumping test, whereas during the experiment the specific capacity was 7.0 $m^3/h.m$. The difference could be associated with the different rates of pumping and recharge 26 m^3/h and 20 m^3/h, respectively. It is concluded that, under the same water level variations in the borehole B1, the pumping rate is smaller than the injection rate.

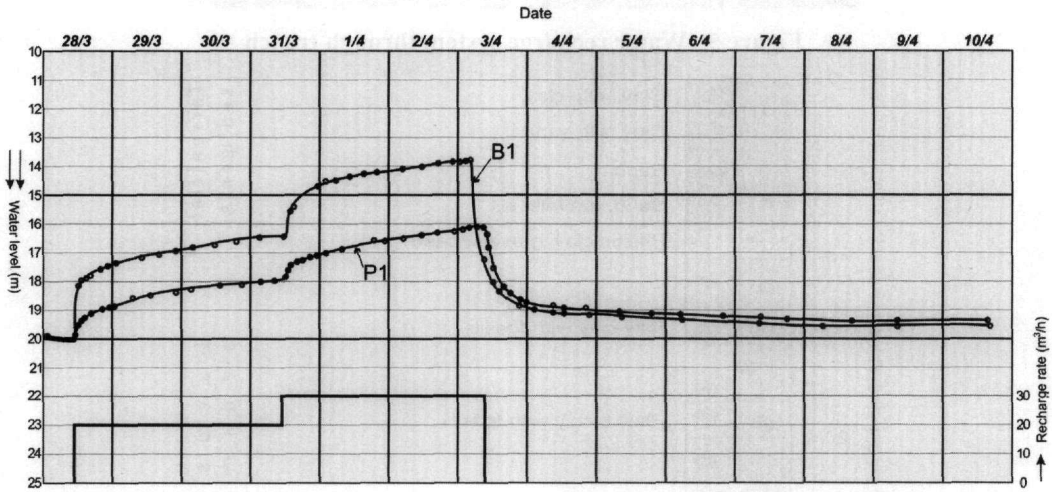

Figure 7–Fluctuation of groundwater level during the recharge in borehole B1

4.2. Recharge from a trench

The width of the trench was approximately 2 m and the length 110 m; consequently the recharge area was 200-220 m^2. The depth of recharge water was 0.15-0.20 m. As it is aforementioned, the recharge rate was 45 m^3/h during the first six days and 60 m^3/h during the last day. It is concluded that, the rate of water absorption was 0.20-0.25 m^3/h per m^2 or 0.20-0.25 m/h.

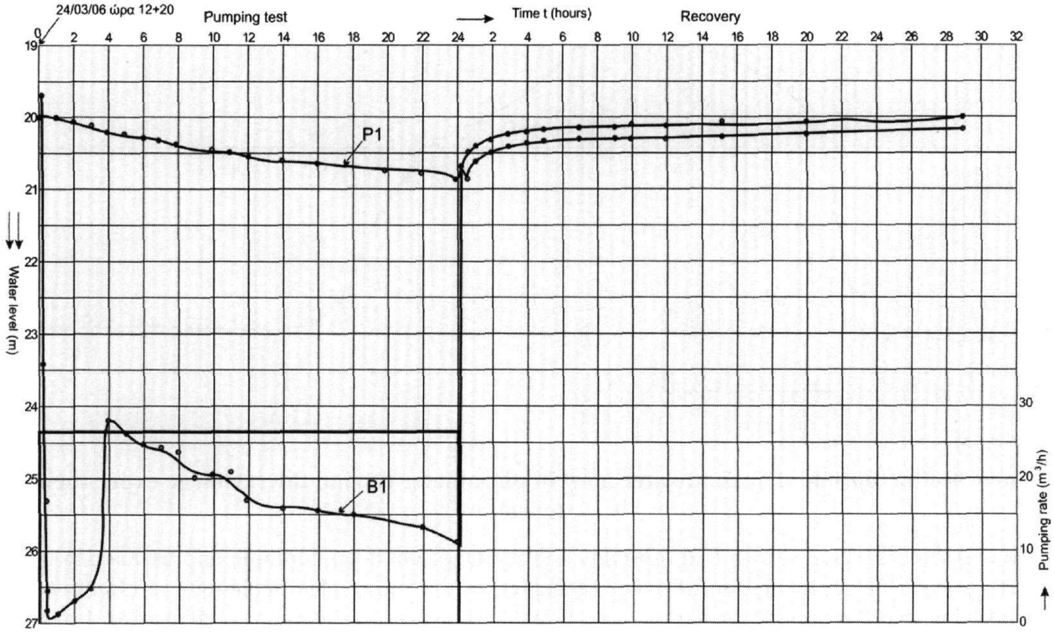

Figure 8 – Fluctuation of groundwater level in borehole B1 and piezometer P1 during the recharge experiment and recovery

Table 2- Results of the recharge experiments

Recharge method	Rate (m^3/h)	Duration (days)	Total volume of recharge water (m^3)	Water level rise* (m)
Borehole	20 and 30	7	4,080	3.78
Trench	45 and 60	7	7,920	13.0

* In piezometer at distance of 15-18 m at the end of the experiments

The water level rise in piezometer at a distance of 15 m is recorder 60 h after the beginning of the experiment (Fig. 9). The water level stabilized 6 days after the end of the recharge, 0.70 m higher than the beginning of the experiment.

5. Conclusions

Recharge experiments through deep borehole, drilled in alluvial deposits and trench were carried out in Larisa prefecture during the March-April 2006. These experiments aimed at getting insight into the feasibility of recharging aquifers with surface water.

The duration of the recharge experiments was 7 days. The total volume of recharge water in the borehole and trench was 4,080 m^3 and 7,920 m^3, respectively.

The maximum rise of the groundwater level at the end of the test was 4.5 m in the injection borehole. This field test showed that, recharge rate was about 20 m^3/h. The water absorption in trench was 0.20-0.25 m^3/h per m^2 or 0.20-0.25 m/h.

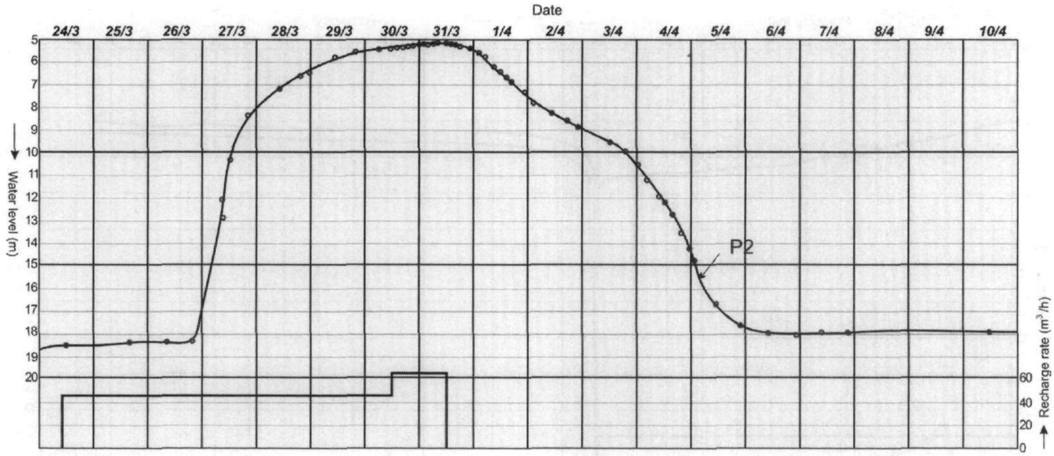

Figure 9–Fluctuation of groundwater level in piezometer during the recharge experiment in trench

Field experiments have shown that, groundwater recharge via deep borehole and trench can be an effective mean of augmentation of water resources in the future. The technique is effective and feasible and may be applied as part of a sustainable water resources management plan, based on surface and groundwater exploitation, simultaneously.

Further analysis is required to assess the longer-term behaviour of the injection borehole and hydraulic parameters of the aquifer. This may involve simulation of groundwater flow and extended field experiments.

6. Acknowledgements

This research was supported by the Region of Thessaly.

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