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CONTRIBUTION TO HYDRAULIC CHARACTERISTICS OF PLIO-PLEISTOCENE DEPOSITS OF THRIASSION PLAIN OF ATTICA

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Abstract

The geological structure of Thriassion Plain is generally complex and has been affected at different times by many tectonic activities. The last ones are the neotectonic, which caused horsts and grabens structures. Geologic and tectonic structures have influenced the hydrogeological conditions and the groundwater flow. Hydraulic characteristics of Plio-Pleistocene deposits differ throughout their extent. In this study, pumping tests in Plio-Pleistocene deposits are represented and the hydraulic characteristics transmissivity T, storativity S and hydraulic conductivity K are assigned. Pumping tests, in 8 totally wells, were conducted in the dry period. Methods as Cooper-Jacob's, Theis's, Papadopoulos-Cooper's and Neuman's and last the Recovery method, are used to assign the hydraulic characteristics. These tests highlighted the Recovery method as the most reliable. Transmissivity T: 18-279.1 m^2/d, storativity S: $2.5*10^{-3}$-$3*10^{-2}$and hydraulic conductivity K: 0.4-25.1 m/d. Specific capacity is also determined ranging between 16-360 m^3/d/m. This study contributes, essentially, in the approach of hydrogeological conditions of Thriassion Plain.
Keywords: *Quaternary sediments, Groundwater pumping test.*

Περίληψη

Η γεωλογική δομή της ευρύτερης περιοχής του Θριασίου Πεδίου είναι σε γενικές γραμμές πολύπλοκη και έχει επηρεασθεί σε διάφορες περιόδους από σύνθετες τεκτονικές δράσεις και τελευταία από την νεοτεκτονική, η οποία έχει δημιουργήσει πολύ σύνθετες δομές κεράτων και βυθισμάτων. Η γεωλογική και τεκτονική δομή έχει επηρεάσει τις υδρογεωλογικές συνθήκες και την κίνηση του υπόγειου νερού. Τα υδραυλικά χαρακτηριστικά των πλειο-πλειστοκαινικών ιζημάτων διαφέρουν από θέση σε θέση. Σε αυτό το άρθρο παρουσιάζονται αποτελέσματα αντλητικών δοκιμασιών που πραγματοποιήθηκαν στις πλειο-πλειστοκαινικές αποθέσεις και προσδιορίσθηκαν τα υδραυλικά χαρακτηριστικά τους. Οι αντλήσεις πραγματοποιήθηκαν σε 8 πηγάδια και εφαρμόσθηκαν οι μέθοδοι Cooper-Jacob, Theis, Papadopoulos-Cooper, Neuman και η μέθοδος της Επαναφοράς. Οι αντλήσεις αυτές ανέδειξαν την μέθοδο της Επαναφοράς ως την πλέον αξιόπιστη. Η μεταβιβαστικότητα T κυμαίνεται μεταξύ 18-279.1 m^2/d, η αποθηκευτικότητα S μεταξύ $2.5*10^{-3}$-$3*10^{-2}$ και η υδραυλική αγωγιμότητα K μεταξύ 0.4-25.1 m/d. Επίσης, προσδιορίσθηκε η ειδική ικανότητα, η οποία κυμαίνεται μεταξύ 16-360 m^3/d/m. Η έρευνα αυτή συμβάλλει, ουσιαστικά, στην προσέγγιση των υδρογεωλογικών συνθηκών που επικρατούν στο Θριάσιο Πεδίο.
Λέξεις κλειδιά: *Τεταρτογενή ιζήματα, δοκιμαστικές αντλήσεις.*

1. Introduction

Estimation of groundwater potential of an area is achieved by the determination of the hydrogeological regime as well as the calculation of hydraulic characteristics of the aquifers, transmissivity T, storativity S and hydraulic conductivity K. Specific capacity Q/s is of great value as well. The most reliable way to determine hydraulic parameters of the aquifer is pumping tests. In this way it is obtained an average value of these parameters as it is assumed that water moves through the total porosity (primary and secondary). The results from pumping tests outline the actual groundwater flow. This method is more accurate than the estimation of hydraulic parameters from laboratories measurements. These samples are never undisturbed (Driscoll, 1986). Many methods are used to analyze and evaluate pumping test data. Determination of the hydraulic characteristics is based on mathematical equations and analytical solutions. They are based also on the knowledge of geological structure and the processes that form aquifers as well as hydrogeological conditions that influence the variation of the piezometric level during the tests. These aquifers tests can also predict: a) the effect of new withdrawals on existing wells, b) the future drawdown in a well, c) the radius of influence of a well (Driscoll, 1986). In this article pumping tests in Plio-Pleistocene deposits of Thriassion Plain are represented. Hydraulic characteristics transmissivity T, storativity S and hydraulic conductivity K are assigned, using several methods and taking into account the average values (Driscoll, 1986; Kruseman et al., 1990). This study refers to the research of geohydraulic characteristics of the aquifers in Plio-Pleistocene deposits of Thriassion Plain for a better approach of hydrogeological conditions of the above area. Pumping test data are part of the doctoral thesis that is carried out in the above area (Hermides, 2016).

2. Study area

The geological structure of Thriassion is generally complex and has been affected at different times by many tectonic activities. The last ones acted in Pleistocene which caused horsts and grabens structures.

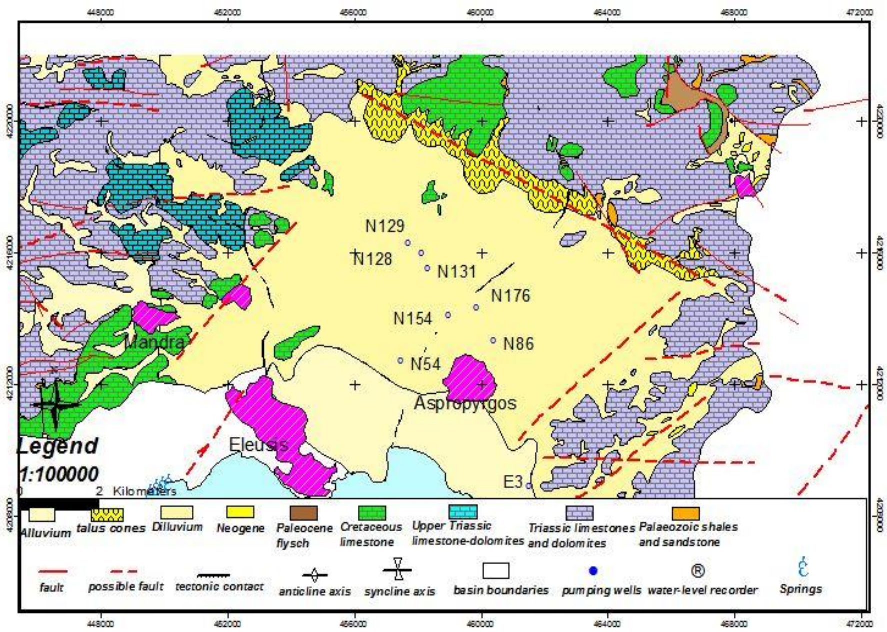

Figure 1 - Geological map of study area and points of pumping wells (IGME, Katsikatsos *et al.*, 1986).

The wide area consists of Palaeozoic volcano sedimentary complex of: a) clastic materials such argillaceous shales and sandstones, which alternate with grauwackes and conglomerates b)basic-igneous volcanic rocks c) limestones, Triassic limestones and dolomites, Cretaceous limestones, Paleocene flysch, Plio-Pleistocene deposits of Pliocene marls, sandstone, marly limestone and Pleistocene argyles, sands, gravels, torrential fans of loosely and cohesive conglomerates and to the top alluvial deposits of argyles, loams, sands and gravels. The largest percentage of the wider area is mountainous with steep slopes and deep ravines, plains grow at altitudes from 0 to 100m, in Thriassion Plain, area of approximately 100 km2 presented by diluvium (Figure 1). This is a tectonic sinking which formatted during the Neogene and filled with terrestrial, lacustrine and marine deposits which thickness is over than 400m. Geologic and tectonic structures have influenced the hydrogeological conditions and the groundwater flow. Hydraulic characteristics of Plio-Pleistocene deposits differ throughout their extent. Pumping tests have been conducted by a few researchers in the past, in limestone and in quaternary deposits.

3. Materials and Methods

Pumping tests were carried out following most of the rules that required producing accurate data and determine as much as possible more actual values of the hydraulic characteristics of wells and the aquifer. The piezometric surface was at the normal static level, the discharge rate was constant and the water was piped far enough from pumping well, water level was recorded at regular intervals, the measuring of the drawdown was taken carefully, the measuring device was the same each time. Unsteady-state flow methods were used for both confined and unconfined aquifers. Theis's (1935) Cooper-Jacob's (1946), Neuman's (1972), Papadopulos-Cooper's (1967) methods were used as well the method of Recovery. The duration of pumping tests ranges between 6-12 hours, however, transmissivity is accurately determined. The methods presented in this article are based on the following assumptions (Theis, 1935):

1 The aquifer is confined and has an infinite extent.
2 The aquifer is homogeneous and isotropic and of uniform thickness around the area influenced by the pumping test.
3 Before the test, the piezometric surface is horizontal or nearly horizontal in the area affected by the test.
4 The aquifer is pumped at a constant discharge rate during the test.
5 The well penetrates the entire aquifer and receives water from the entire saturated thickness of the aquifer.
6 Water is been removed instantaneously from the aquifer by the pumping.
7 The aquifer is not supplied from any source during the test.
8 The flow towards the pumping well is horizontal.
9 The parameter u, in the Cooper-Jacob's method, must be smaller than 0.01.
10 The well diameter is small (not for Papadopoulos-Cooper method).

The main problem in the area of Thriassion focuses on the fact that the geological structure is complex and actual thickness of the aquifers cannot be accurately determined, because of the following:

- There are not several lithological cross-sections of wells in the area.
- None of such a well has penetrated the whole aquifer system.
- The thickness differs from site to site.

Therefore the following assumptions were adopted:

- The wells penetrate the entire thickness. This is not far from reality because thicknesses are small in general and one to three aquifers often is pumped.
- The total thickness of all aquifers is the sum of the individual aquifer thicknesses.

- The thickness is uniform in the area influenced by the test, which is largely true.

For Cooper-Jacob's method the condition u<0.01 is rather rigid. For 5 or 10 times higher value u<0.05 or u<0.1 the error introduced in the result is less than 2% or 5%, respectively. For practical purposes it is suggested using u<0.05 (Driscoll, 1986) or u<0.1 (Kruseman *et al.*, 1990). Specific capacity was calculated using the predicted drawdown s, after extension to 24 hours pumping, using the equation of the line regression from the graph or using the equation 1 of theoretical drawdown:

Equation 1 theoretical drawdown s

$$s = 0.183 * \frac{Q}{T} * \log(2.25 * \frac{Qt}{r^2 S} s = 0.183 * \frac{Q}{T} * \log(2.25 * \frac{Q * t}{r^2 * S})$$

In aquifers of Thriassion, pumping tests were conducted in the wells:

- N54, N86, N128, N129, N131, N154, N154 Π-2, N176 by the writer
- in the group of the wells E (4 wells) by IGME

Many graphs were accomplished and all pumping data were analysed with all the methods and finally an average result of the calculations is presented to obtain as the most accurate values as possible (Kruseman *et al*., 1990).

4. Results

4.1. Evaluation of pumping test data

4.1.1. Well Nr54

The test was conducted on 05/29/2012, the duration of it was 12 hours and the drawdown was 0.86 m. Thickness of the aquifer is 5m data were analysed with all methods and finally, Papadopoulos's, Neuman's and the Recovery methods were chosen (Figure 2). The aquifer which is tapped by well Nr 54 is unconfined. This is proved from the fact that the annual water level fluctuation is about 0.45m. The conditions around the well N54-Π1 at distance 65m faraway show confined aquifer and the well Nr54-Π2 at distance 125 m faraway show semiconfined aquifer, as the storativity value deduced from analysis of the observing wells Π1 and Π2 ranges between 2.8*10-3 and 9.8*10-3, respectively (Figure 3).

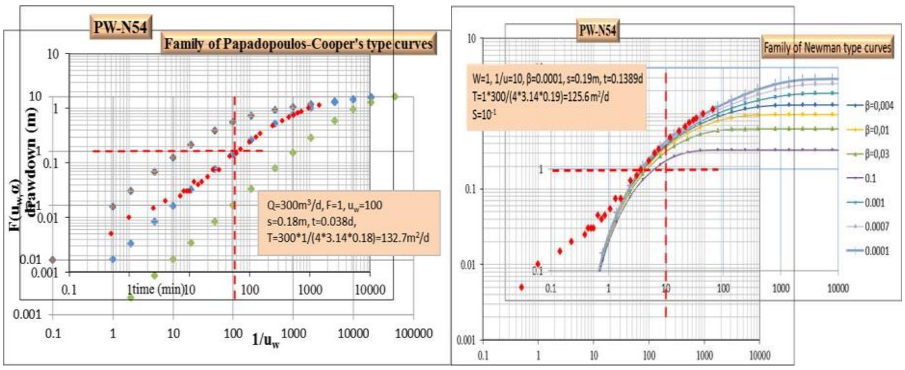

Figure 2 - Analysis of pumping test data of well N54 after Papadopulos-Cooper's and Neuman's method.

In Figure 3 it is shown a clear example of a transient steady-state flow. For an hour the drawdown of the two observation wells P1 and P2, located 60 m between them, have the same rate without reaching the equilibrium. In Figure 4 is shown pumping test data of the observation well P2 analyzed with Theis's method. In the same Figure 4 it shown a typical case where it could be given incorrect interpretation because it is displaced the phenomenon of pseudo-transmissivity where data are affected by storage effects (the first segment in Figure 3) and recharge effects (the horizontal segment) (Worthington, 1981). The value of transmissivity deduced after Papadopulos-Cooper's method was T=132.7 m2/d, after Neuman's method was T= 125.6m2/d and by the Recovery method was T=129.1m2/d. It is strongly obvious that T=129.1m2/d Storativity around the well Nr 54 is S=6.2*10-3revealing a semiconfined aquifer, hydraulic conductivity was K=25.1 m/d and specific capacity was calculated Q/s=294m3/d/m.

4.1.2. Well Nr 86

The test was conducted on 10/19/2011, the duration of it was 6 hours and the drawdown was 1.12m. Thickness of the aquifer is 15m Data were analysed using all methods and finally, Papadopoulos-Cooper's, Cooper-Jacob's and the Recovery methods were chosen. In Figure 5 it appears a clear example of pumping test data where the storage effect in the well affected the discharge rate and if it is not been taken into account the estimation of transmissivity will be erroneous.

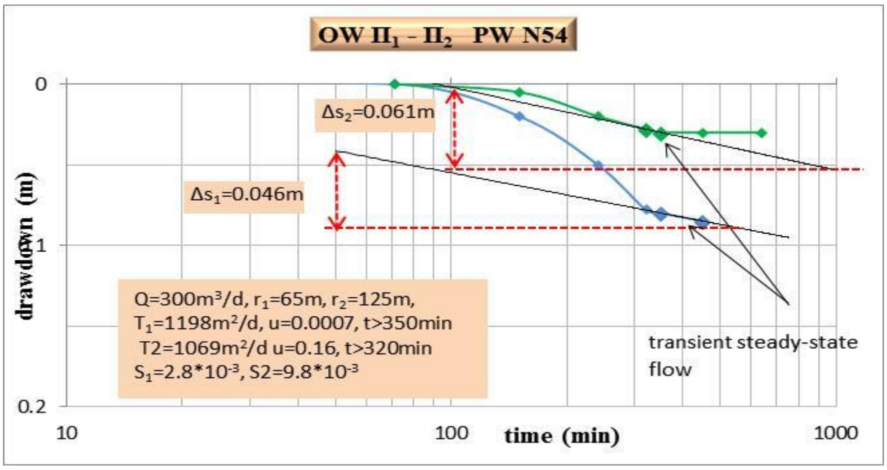

Figure 3 - Pumping test data for the observation wells Π1-Π2 and development of a transient steady-state flow (Cooper-Jacob's method).

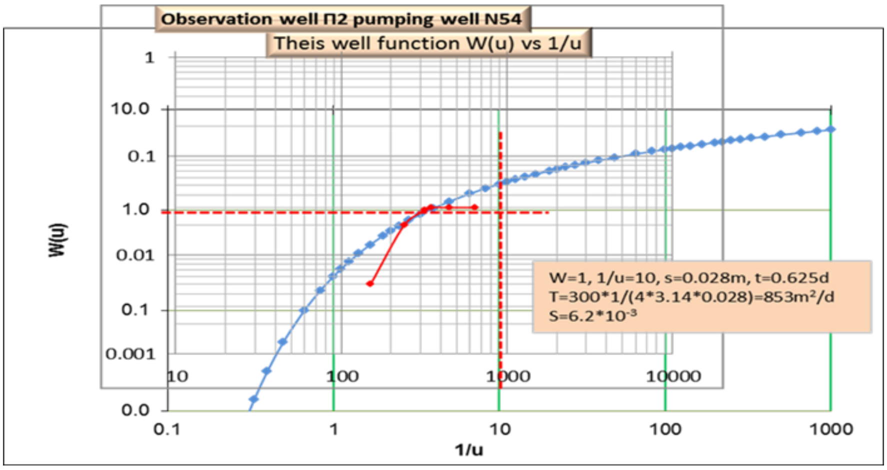

Figure 4 - Pumping test data of the observation well P2 and detection of pseudo-transmissivity (Theis's method).

The value of transmissivity deduced after **Papadopulos-Cooper's method** was **T=270.7 m2/d**, after **Cooper-Jacob's method** was **T= 287.5m2/d** and by the **Recovery method** was **T=279.3m2/d.** It is remarkable that the average value of transmissivity **T=279.1m2/d** coincides with the Recovery value. Storativity around the area of well Nr 86 is **S=5.3*10-3** revealing a semiconfined aquifer, hydraulic conductivity was **K=23.25 m/d** and specific capacity was calculated at **Q/s=300 m3/d/m**. Storage effects in the pumping well has been analysed by Schafer's equation 2 (Schafer, 1978).

Equation 2 Schafer's equation of calculating time t when storage in the well is negligible

$$t_c = 0.017\frac{(d_c^2 - d_p^2)}{\frac{Q}{s}}$$

Where:

t_c= time when storage effect in the well becomes negligible in minute

d_c = diameter of unscreened well in mm

d_p = outside diameter of pump pipe in mm

Q/s= specific capacity in m^3/d/m

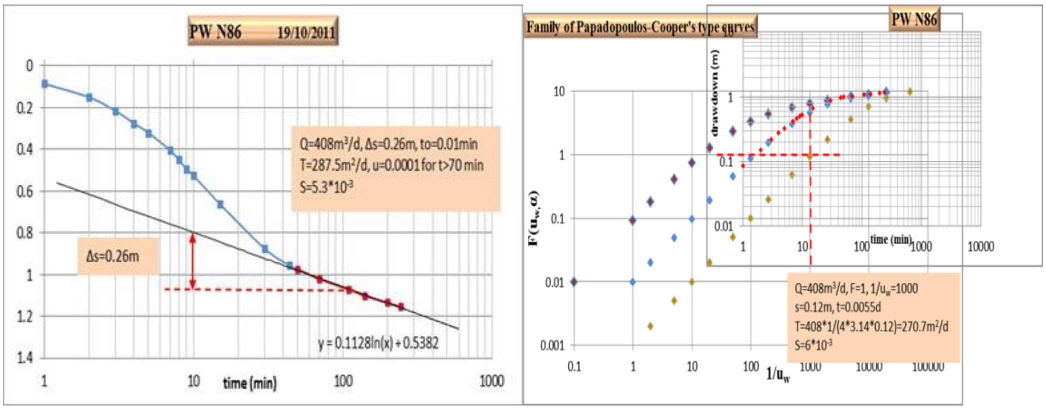

Figure 5 - Pumping test data of the pumping well Nr 86 (Cooper-Jacob's and Papadopulos-Cooper's method).

4.1.3. Well Nr 128

The test was conducted on 10/28/2008, the duration of it was 6 hours and the drawdown was 6.77m. Thickness of the aquifer is 15m. Data were analysed using all methods and finally, Papadopulos-Cooper's, Neuman's, Cooper-Jacob's and Recovery methods were chosen. The value of transmissivity deduced after Theis's method was **T= 25.5 m2/d**, after Neuman's method was **T= 22.5m2/d** (Figure 6), after Papadopulos-Cooper's method **T=34.7m2/d** and by the Recovery method was **T=30.1m2/d** (Figure 7). Transmissivity value is finally **T=30.1m2/d**. Hydraulic conductivity calculated at the value of **K=2 m/d** and specific capacity at the value of **Q/s=52 m3/d/m**. Papadopulos-Cooper's method gave a value of storativity **S= 1.9*10-2**. This value reveals an unconfined aquifer; however the aquifer is under pressure in general, which is proved by the high piezometric level of +9.5 m and the annual fluctuation of about 5 m. The answer in this discrepancy of results is that the time of pumping in October the aquifer behaved as unconfined due to the generally drawdown of the piezometric surface.

4.1.4. Well Nr 129

The test was conducted on 10/29/2008, the duration of it was 5 hours and the drawdown was 6.77m. The thickness of the aquifer is about 15 m. The estimated value of transmissivity taking into account the Theis's, Cooper-Jacob's and Recovery methods was **T = 18 m2/d**. This value of transmissivity combined with the large drawdown of about 10 m reveals an aquifer of low capacity and it is very likely to locate at the border of the Plio-Pleistocene deposits. Hydraulic conductivity calculated at the value of **K=0.4 m/d** and specific capacity at value **Q/s=16m3/d/m.**

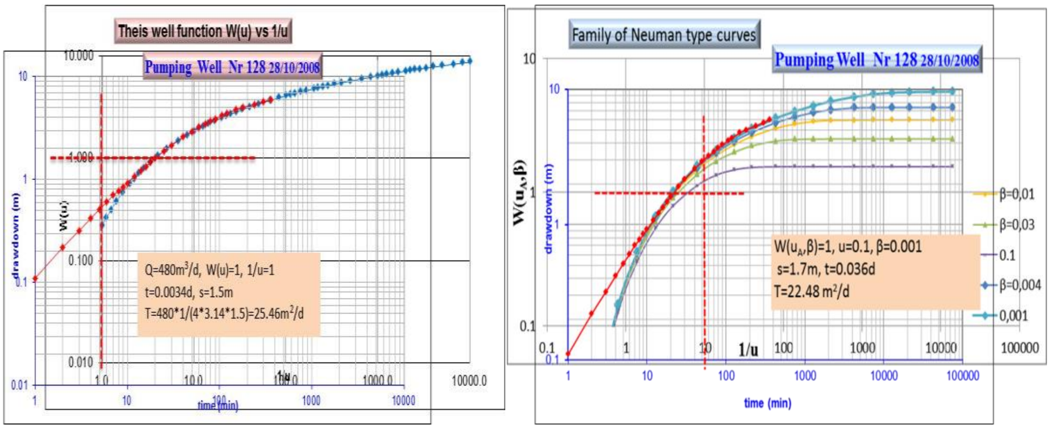

Figure 6 - Pumping test data of well Nr 128 (Cooper-Jacob's and Neuman's method).

4.1.5. Well Nr 131

The test was conducted on 10/28/2008, the duration of it was 5 hours and the drawdown was 2.44m. The thickness of the aquifer is about 15 m and pumping test data have been taken only by the recovery phase. Transmissivity value was estimated at the value of **T =32.52m2/d** (Figure 8a). Drawdown was 4.66 m after 5 hours pumping. Discharge rate was **Q = 408 m3/d.** Aquifer is confined and the piezometric level is at +9 m. Specific capacity was estimated at the value of **Q/s= 50 m3/d/m**.

4.1.6. Well Nr 154

The test was conducted on 04/05/2009, the duration of it was 6 hours and the drawdown was 1.31m The thickness of the aquifer is about 10 m. Transmissivity value obtained after Theis's method was **T=104.6 m2/d**, after Cooper-Jacob's method was **T=**104.7m2/d, by the Recovery method was **T =105.4 m2/d** and after Neuman's method **T=108.3m2/d.** The average value was **T= 105.8m2/d.** Drawdown was 1.31 m after 6 hours pumping. The aquifer is unconfined and storativity obtained after Papadopulos-Cooper's method **S = 2.8*10-2.** Hydraulic conductivity **K= 10.58 m/d** (Figure 8b). Specific capacity was calculated at the value of **Q/s= 247 m3/d/m.**

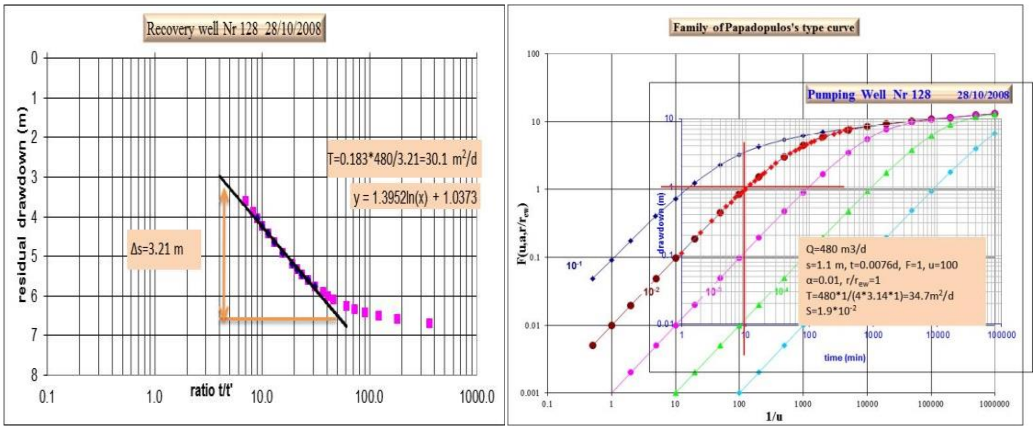

Figure 7 - Pumping test data of well Nr 128 (Recovery, Papadopulos-Cooper's methods).

4.1.7. Well Nr 154-П2

The test was conducted on 04/05/2009, the duration of it was 3 hours because the pump was broken and the drawdown was 1.29 m. Transmissivity value obtained after Papadopulos-Cooper's method was **T=228 m2/d,** by Recovery method **T =238.6 m2/d** and Neuman's method **T=228.3m2/d**. The average value **T= 231.6m2/d.** Drawdown was 1.255 m after 3 hours pumping. The aquifer is unconfined and storativity is **S = 3*10-2**. Hydraulic conductivity **K= 15.44 m/d**. Discharge rate was **Q=516 m3/d** (Figure 9). Specific capacity was estimated at the value of **Q/s= 360 m3/d/m.**

4.1.8. Well Nr 176

The test was conducted on 10/02/2000, the duration of it was 5 hours and the drawdown was 3.86m. Transmissivity value obtained after Papadopulos-Cooper's method was **T=57.3 m2/d**, after Recovery method **T =56.7 m2/d** and Neuman's method **T=52.1m2/d.** The average value was **T=55.4m2/d.** Drawdown was 3.86 m after 5 hours of pumping. The aquifer is confined and storativity is **S = 2.5*10-3**. Hydraulic conductivity **K= 11.08 m/d**. Discharge rate was **Q=720 m3/d** (Figure 10).

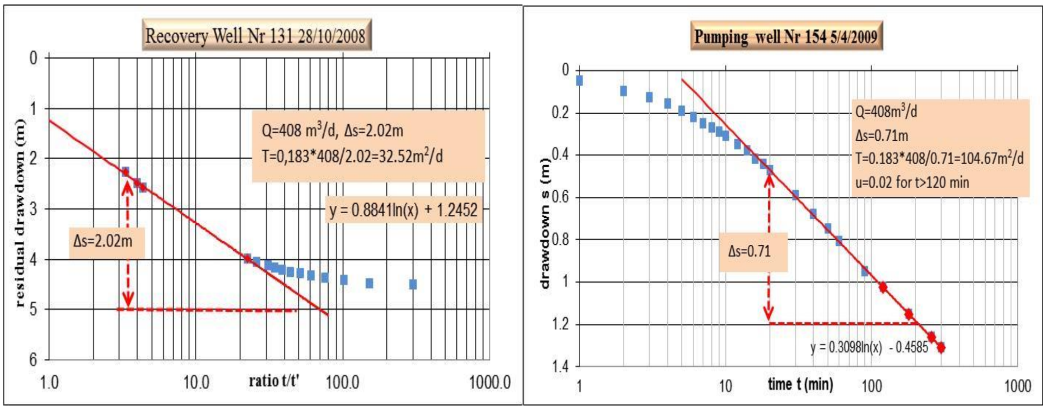

Figure 8 a, b - Pumping test data of well Nr 131 and Nr 154 (Recovery and Cooper-Jacob's method respectively).

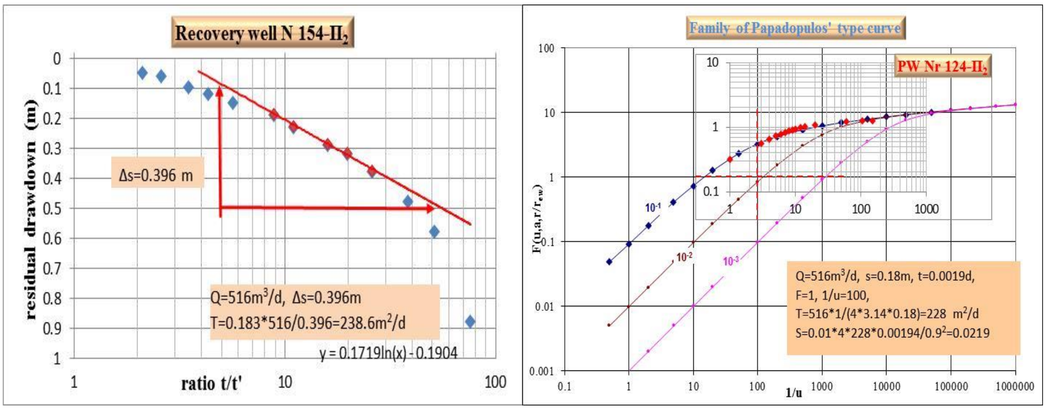

Figure 9 - Pumping test data of well Nr 154-P2 (Recovery and Papadopulos-Cooper's method respectively).

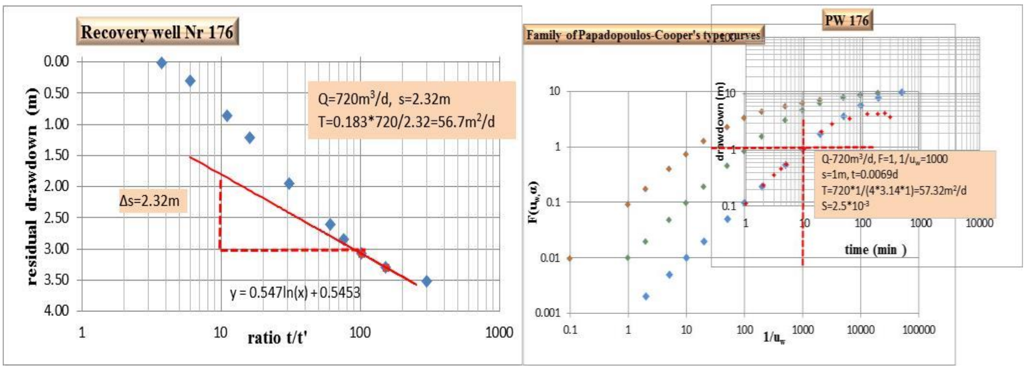

Figure 10 - Pumping test data of well Nr 176 (Recovery and Papadopulos-Cooper's method respectively).

Table 1 summarizes the hydraulic characteristics of 8 wells that have been pumped in Thriassion Plain.

Table 11 - Summary of hydraulic characteristics of wells in Plio-Pleistocene deposits of Thriassion Plain.

Well Nr	T (m^2/d)	S	K (m/d)	Calculated 24 h Q/s (m^3/d/m)
N54	129.1		25.1	294
N54-Π2		$2.8*10^{-3}$		
N86	279.1	$5.3*10^{-3}$	23.25	300
N128	30.1	$1.9*10^{-2}$	2	52
N129	18		0.4	16
N131	32.52		2.17	
N154	105.8	$2.8*10^{-2}$	10.58	247
N154-Π2	231.6	$3*10^{-2}$	15.44	360
N176	55.4	$2.5*10^{-3}$	11.08	186
average	**110.2**		**11.25**	**207.86**

5. Conclusions

This study presents pumping tests in wells in Plio-Pleistocene deposits of Thriassion Plain of Attica which conducted in the period 2008-2012 and one test in 2000. None of important changes in climatic conditions or other environmental impacts occurred during this period that could affect the hydraulic characteristics of Triasssion Plain. Concluding after all these data, it is obvious that the aquifers, in the above mentioned area, are under unconfined, confined and semi confined conditions. These results are actually reasonable in terrestrial Pleistocene deposits within there are clay layers. The values of transmissivity **T** ranges from **8-279.1 m2/d,** storativity S ranges from **2.5*10-3 -3*10-2**, hydraulic conductivity **K** ranges from **0.4-25.1 m/d** and specific capacity **Q/s** ranges from **16-360 m3/d/m.**

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