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FLOW TEST EVALUATION OF THE FRACTURED FILIATRA KARST AQUIFER

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ABSTRACT

The fractured Filiatra Eocene limestones comprise a karstic reservoir of limited amount of fresh water. Five test wells drilled in this aquifer were pump tested until a pseudosteady state was achieved after a relatively short period of time. The semilog plots of these well tests are influnced by the wellbore storage as well as by the double porosity of the aquifer. Using the double porosity model and considering Darcian flow through the fracture media, the calculated aquifer parameters for these limestones are: transmissivity from $0.10x10^{-1}$ to $0.27x10^{-3}$ m^2/s, and specific capacity from $0.26x10^{-1}$ to $0.16x10^{3}$ m^2/day.

INTRODUCTION

Ten test boreholes were sunk into the karstified Filiatra limestones by the Land Reclamation Survey of the Ministry of Agriculture. The shallowest (G-9) being 85m deep and the deepest (G-18) 151m deep. They were located on the western flank of the Filiatra anticline (Figure 1). Five of them (G-2, G-9, G-4, G-27 and G-5) were considered productive, whereas four (G-11, G-3, G-6 and G-18) were considered abortive due to their very low yield. Well G-10 although having a high yield was considered unsuccessful due to its high NaCl content. The overlying neogene fine grained sediments encountered in some wells, were isolated.

The groundwater flow in fractured aquifers has been studied by the assumption of a continuum representation of the medium by using the double-porosity approach. This model introduced first by Barenblatt et al (1960), is used to simulate the heterogeneity of the fractured formations. According to this theory, the fractured formation is considered to consist of blocks of porous rock matrix separated by a network of interconnecting fractures. The permeability of the porous block is assumed to be small and the movement of the water to pumped wells is assumed to be small. Hence, the movement of the water to production wells is considered to be entirely through fractures. Moreover, it is also considered that the blocks of porous matrix, which have some primary porosity and a very low permeability, act only like sources which feed the fractures with water.

Two approximations are used to describe this leakage from porous matrix blocks to fractures. The first, known as approximation of quasi-steady state flow, is based on the assumption that the flow depends on the difference between the head in fractures andthe average head in blocks. The second (known as approximation of unsteady state flow) is based on the unsteady flow in po-

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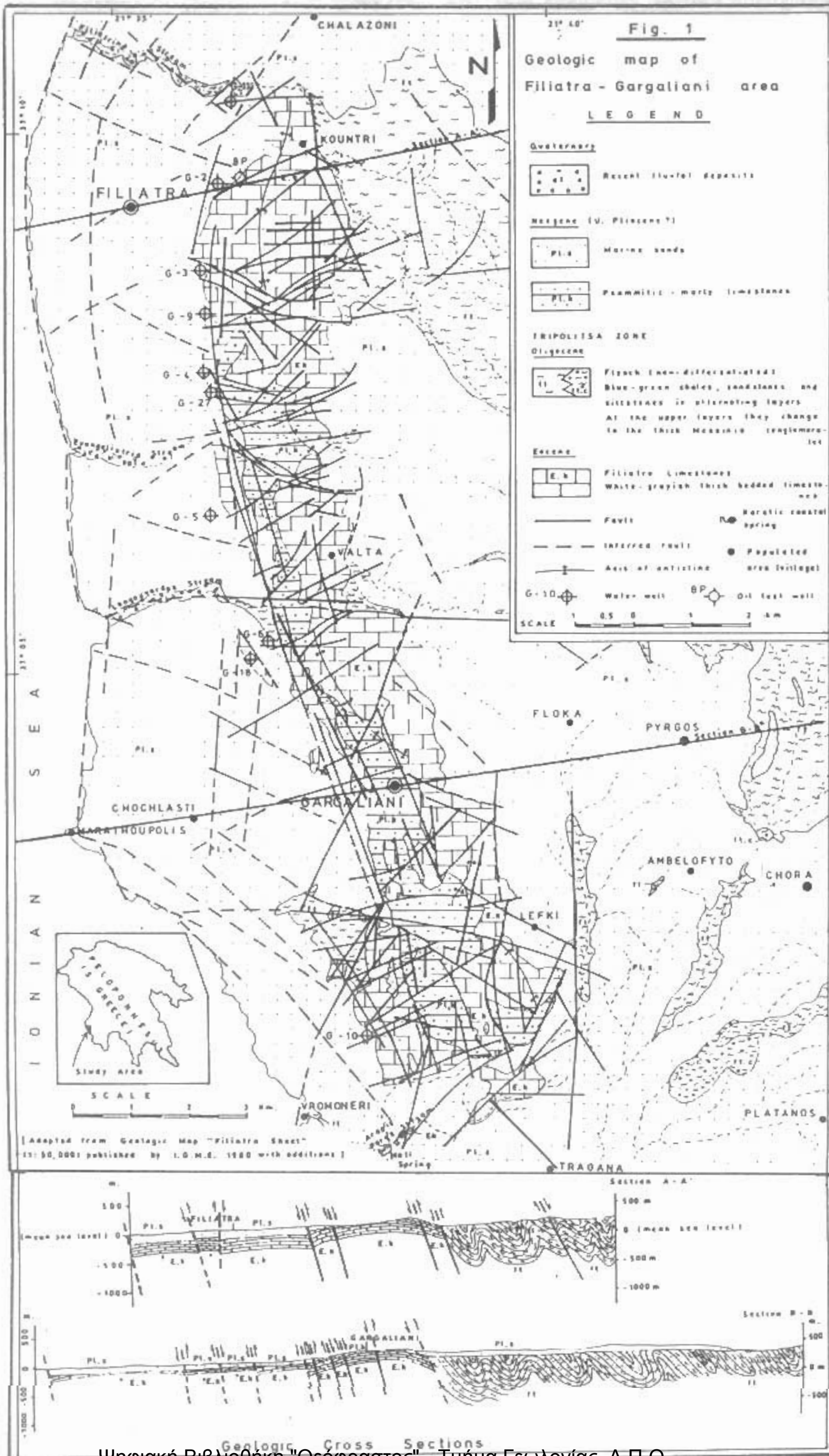
Fig. 1: Geologic map of Filiatra - Gargaliani area



rous matrix blocks. Various workers on flow through fractured media such as Duguid and Lee (1977), Boulton and Streltsova (1977), Huyakorn and Pinder (1983), Huyakorn et al (1983), Kallergis et al (1990), and Tavitian (1993), have developed solutions for such cases using the double porosity model. All of them have considered Darcy flow through the medium of fractures.

GEOLOGIC SETTING

The Filiatra limestone horst-anticline of Eocene age in southwestern Peloponne-sus belongs to the Tripolitsa zone. It is medium-thick bedded bituminous and its thickness reaches up to 300 meters (BP 1971). Compared to other outcrops of Eocene limestones in western Greece, the Filiatra limestones (Figure 1) most likely belong to the Middle Eocene (Lutetian) age. After the somewhat he-terogenous history of deposition and erosion in the late Cretaceous and early Tertiary times there was a return to more widespread and persistant sedimentation (BP, 1971). The rocks are chiefly detrital limestones with rare beds of chert. A bauxite horizon at the Middle and Upper Eocene junction (Koroni-Pylos-Schiza Geological mapsheet, IGME, 1980) probably indicates an intervening phase of weathering. It is thus highly probable that extensive erosion intervened be-tween Lutetian and Bartonian deposition.

FLOW TEST EVALUATION

In well tests of fractured rocks a descriptive approach is a search for a well defined "theoretical reservoir" whose response H to the same stress Q is as close as possible to that of the actual reservoir S. The response of the theoretical reservoir is computed for specific initial and boundary conditions, which must correspond to those of the actual one. This is the "direct problem", H=QS (Kallergis et al 1992).

The log âH vs log ât plot is the best tool for revealing the distinctive impact of the various comonents of the theoretical model. Such components are wellbore storage expressed by proportionality of âH and ât at early times (Ramey 1970, Gringarten et al 1975, Cinco-Lay and Samaniego 1978, Gringarten 1982). This implies that a straight line of unit slope passing through early time data is usually indicative of wellbore storage. A high-conductivity fracture with constant inflow, tapped by a well, yields a log âH-log ât straight line with constant slope. This slope depends on the conductivity of the fracture.

This theoretical model is further complicated in the case of coexistance of one or more of the components with "transitional" radial flow, spherical flow or pseudo-steady-state flow at late time data.

Each pumping test of the five boreholes mentioned is analyzed below and their hydraulic properties are listed in Table 1.

Table 1: Groundwater hydraulic parameters of the Filiatra limestone aquifer.

Well Number	Transmisivity (m^2/s)	Specific Capacity (m^2/day)	Characteristic Graph Equation
G - 2	$0,27x10^{-3}$ to $0,65x10^{-3}$	$0,31x10^{-1}$	-
G - 9	$0,13x10^{-1}$	$0,61x10^{-3}$	-
G - 4	$0,10x10^{-2}$ to $0,08x10^{-2}$	$0,98x10^{-2}$	$\Delta Q = 19,7\ \Delta H$
G - 27	$0,10x10^{-1}$ to $0,35x10^{-1}$	$0,16x10^{-1}$	-
G - 5	$0,29x10^{-3}$ to $0,68x10^{-3}$	$0,26x10^{-1}$	-

(a) Borehole G-2

This well lies 1.5km northeast of Filiatra town. It encountered 4m of upper Pliocene loose sandstones underlain unconformably by 116m of highly fractured and karstified Eocene limestones (Figure 2). The thickness of the saturated zone is 28m.

Figure 3a is the semilog plot of the pumping test data. The drawdown of the single stage 24 hour pumping test with a constant discharge of 22 m^3/hr is 15.76m. Its specific capacity is $0.3x10^{-1}$ m^2/day. The "early time period" lasts less than 3 minutes. At intermediate times (3 to 1380 minutes) the double porosity effect of the fractured and karstified limestones is observed. At relatively longer times (>1380 minutes) the head in the well is stabilized (pseudo-steady-state) which can be attributed to a constant head boundary, and the fractured reservoir behavior is equivalent to a homogenous porous medium.

Figure 3b is the semilog plot of the recovery test. During the "early time period" (first 3 minutes) recovery is relatively fast. The residual drawdown during the first 3 minutes is 0.08m. At intermediate times from (3 to 165 minutes) there is a transition from fracture flow to double porosity flow during which the residual drawdown remains constat. At 180 minutes of recovery the recovery of the initial head is restored.

Figure 3c is a blow up plot of the axis of the residual drawdown at intermediate times of the recovery test showing clearly the double porosity effect which is not so clear in figure 3b.

The transmissivity of this fractured karstic Eocene limestone as calculated, ranges from $0.27x10^{-3}$ to $0.65x10^{-3}$ m^2/s.

(b) Borehole G-9

This well lies 2km southeast of Filiatra. The geological formations encountered are: upper Pliocene 10m thick sediments resting uncorfomably on 75m of fractured and karstified Eocene limestones (Figure 2).

Figure 4a is the semilog plot of the pumping test data. The drawdown of the single stage 12 hour pumpung test with a constant discharge of 61 m^3/hr is 0.09m. Its specific capacity is $0.61x10^{-4}$ m^2/day. The double "porosity effect" of the fractured and karstified Eocene limestones at intermediate times is clearly observed till the period of 360 minutes. At relatively longer times (>360 minutes) the head of the well is stabilized (pseudo-steady-state) which can be attributed to a constant head boundary, and the fractured reservoir behavior is equivalent to that of a homogenous porous medium.

Figure 4b is the semilog plot of the recovery test. As it can be seen from this graph, recovery is rather slow. The transition from fracture flow to double porosity flow is immediate. This lasts for 510 minutes. At 510 minutes the recovery of the initial head of the well is restored.

The transmissivity of this fractured and highly karstified Eocene limestone as calculated is $0.13x10^{-1}$ m^2/s.

(c) Borehole G-4

This well lies 6km southeast of Filiatra. It encountered 42m of upper Pliocene fossiliferous deposits (calcarenites, blue marls, sands and clay) resting unconformably on 65m of fractured and karstified Eocene limestones.

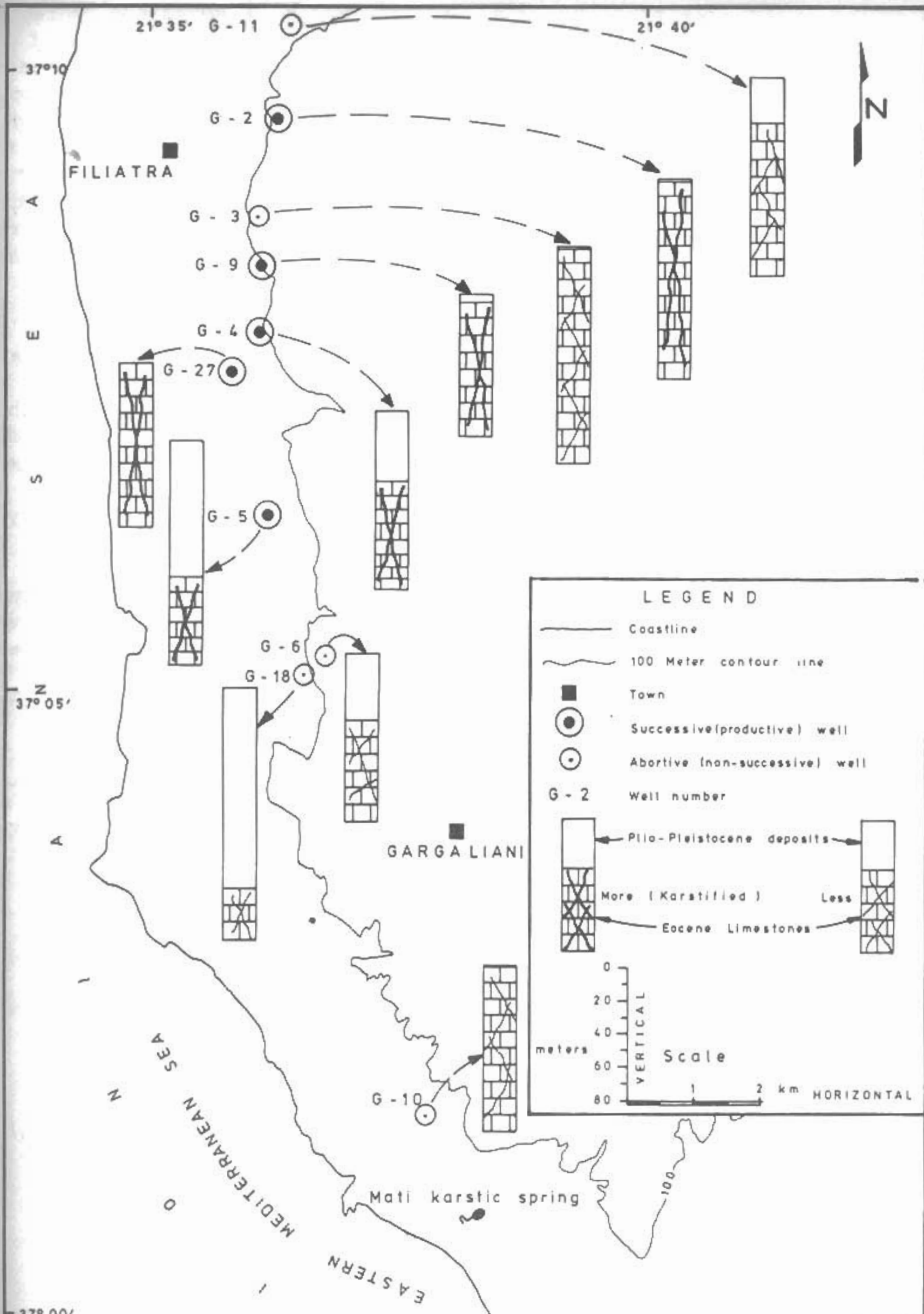


Fig. 2: Lithologic sections of the ten boreholes in Filiatra Eocene Limestones

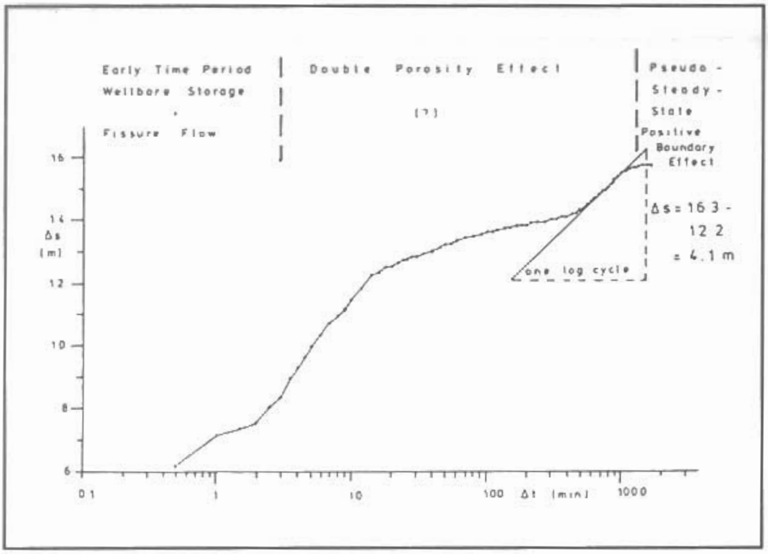


Fig. 3a: Semilog plot of pumping test data of well G-2

Figure 5a represents the characteristic graph of the well ploted from the multi-stage pumping test data (yield vs drawdown). According to this graph the equation relating these two well parameters is $\Delta Q=19.7\Delta s$.

Figure 5b is the semilog plot of the pumping test data. The drawdown of the single stage 24 hour pumping test with a constant discharge of 25 m^3/hr is 5.90m. Its specific capacity is $0.98x10^{-2}$ m^2/day. The "early time period" lasts less than 3 minutes and is entirely dominated by the wellbore storage effect. At intermediate times (3 to 1410 minutes) the double porosity effect of the fractured conglomerates is observed. At relatively longer times (>1410 minutes) the head in the well is stabilized (pseudo-steady-state) which can be attributed to a constant head boundary, and the

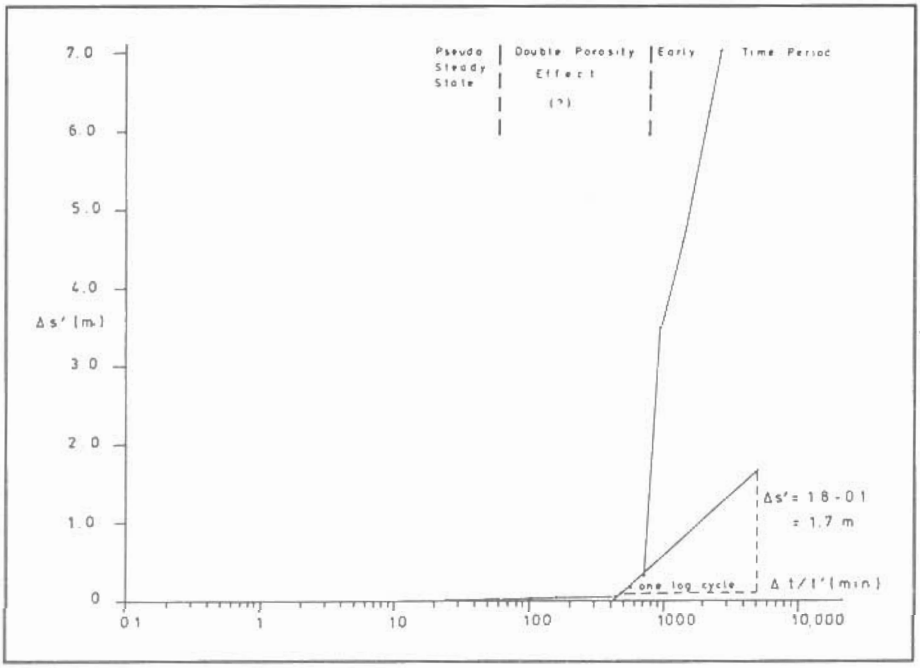


Fig. 3b: Semilog plot of recovery test data of well G-2

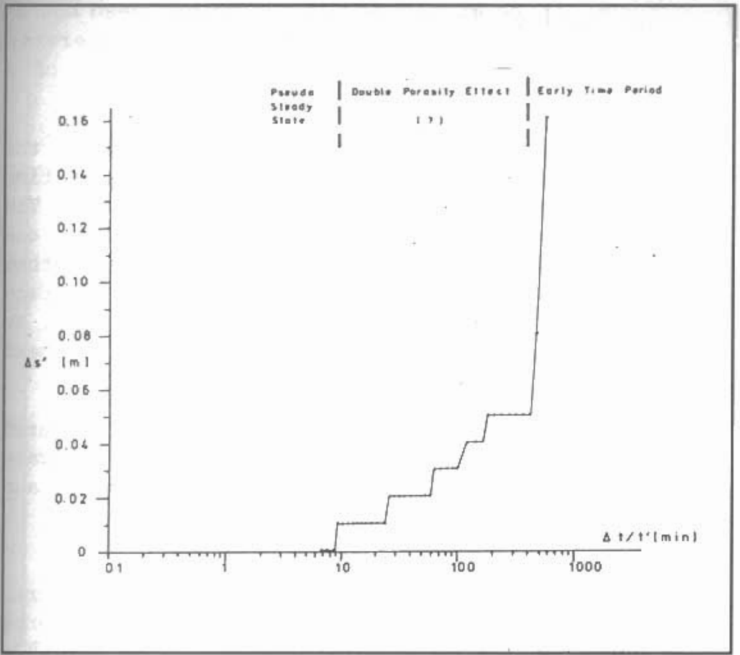


Fig. 3c: Semilog plot of recovery test data of well G-2

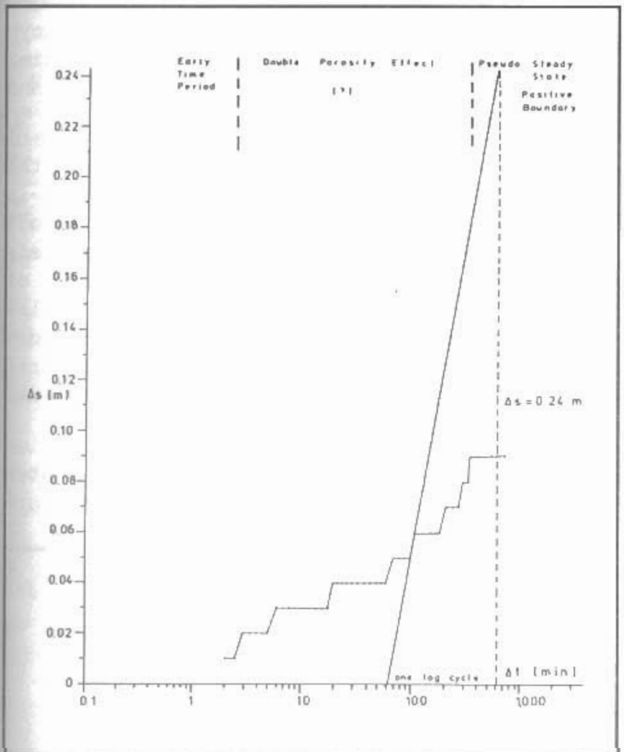


Fig. 4a: Semilog plot of pumping test data of well G-9

fractured reservoir behavior is equivalent to that of a homogenous porous medium.

Figure 5c is the plot of the recovery test. During the "early time period" recovery is very fast. The residual drawdown during the first one minute is 0.90 m. At times greater than this there is a fast transition ftom fracture flow to double porosity flow. At 60 minutes the recovery of the initial head is restored.

The transmissivity of this fractured and karstified Eocene limestone aquifer as calculated varies from 0.10×10^{-2} to 0.08×10^{-2} m^2/s.

(d) Borehole G-27

This well lies 3.5km SSE of Filiatra. It encountered 98m of fractured and karstified Eocene limestones (Figure 2).

Figure 6a is the semilog plot of the pumping test data. The drawdown of the single stage 12 hour pumping test with a constant discharge rate of 120 m^3/hr is only 0.47m. Its specific capacity is 0.16×10^{-3} m^2/day. The "early time flow period" lasts less than 3 minutes and is entirely dominated by the wellbore storage effect. At intermediate times (3 to 540 minutes) the double porosity effect of the fractured and karstified Eocene limestone is clearly seen. At re-latively longer times (>540 minutes) the head of this is stabilized (pseudo-steady-state) which can

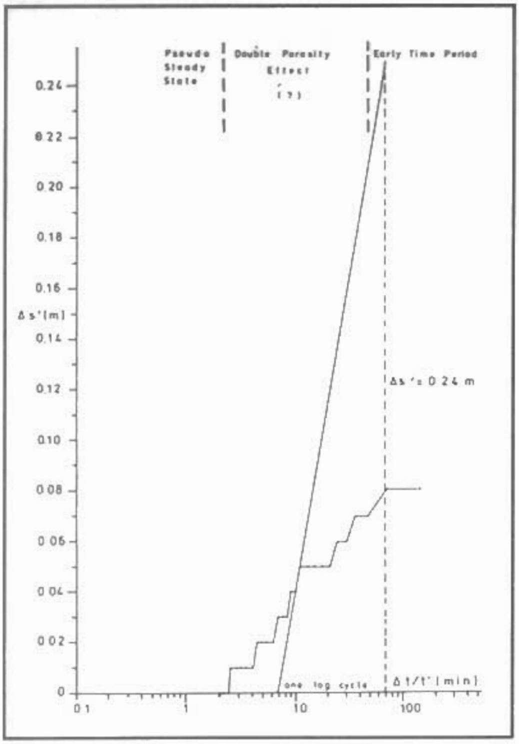


Fig. 4b: Semilog plot of recovery test data of well G-9

be attributed to a constant head boundary, and the fractured reservoir behavior is equivalent to that of a homogenous porous medium.

Figure 6b is the semilog plot of the recovery test. During the "early time flow period" recovery is very fast. The residual drawdown during the first one minute is 0.13m. At times greater than this there is a transition from fracture flow to double porosity flow. At 40 minutes of recovery the initial head of the well is fully recovered.

The transmissivity of this fractured and karstified Eocene aquifer as calculated varies between $0.10x10^{-1}$ and $0.35x10^{-1}$ m^2/s.

(e) Borehole G-5

This well lies 5.5 km SSE of Filiatra. The geological formations encountered until the final depth of 135m are: 97m of upper Pliocene deposits (composed of 15m fossiliferous calcarenites, 75m of marls, pebbles and sands, 5m of clay, and 2m of basal conglomerates) resting unconformably on 38m of fractured and karstified Eocene limestones (Figure 2).

Figure 7a is the semilog plot of the pumping test data. The drawdown of the single stage 12 hour pumping test with a constant discharge of 25 m^3/hr is 15.51m. Its specific capacity is $0.26x10^{-1}$ m^2/day. The "early time flow period" lasts less than 4 minutes and is entirely dominated by the wellbore storage effect. At intermediate times (4 to 690 minutes) the double porosity effect of the fractured and karstified Eocene limestones is clearly observed. At relatively longer times (>690 minutes) the head in this well is stabilized (pseudo-steady-state) which can be attributed to a constant head boundary, and the fractured reservoir behavior is equivalent to that of a homogenous porous medium.

Figure 7b is the semilog plot of the recovery test. During the "early time period" recovery is very fast. The residual drawdown during the first 2 minutes is 0.48m. At times greater than this there is a fast transition from fracture

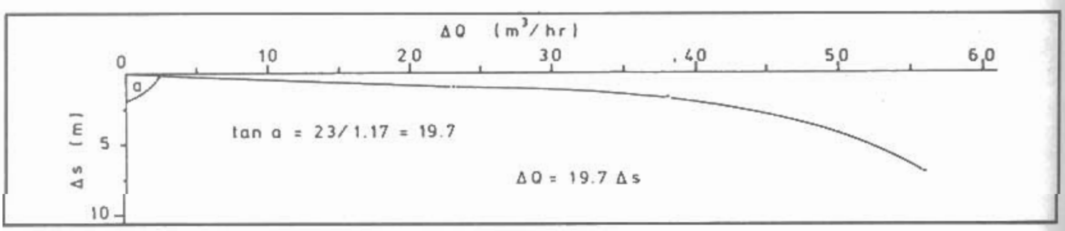


Fig. 5a: Characteristic graph of well G-4 (yield vs drawdown curve)

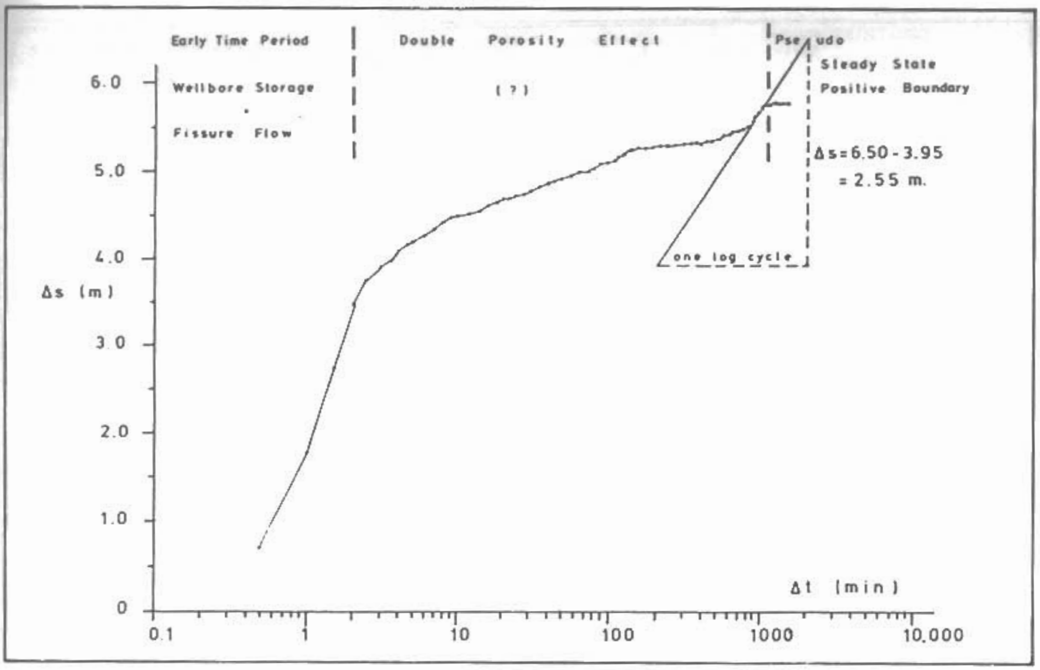


Fig. 5b: Semilog plot of pumping test data of wll G-4

flow to double porosity flow. At 900 minutes the recovery of the initial head of the well is fully restored.

Figure 7c is a blow up plot of the axis of the residual drawdown at intermediate times of the recovery test showing clearly the double porosity effect which is not so clear in figure 7b.

The transmissivity of this fractured and karstified Eocene limestone aquifer as calculated varies from $0.29x10^{-3}$ to $0.68x10^{-3}$ m^2/s.

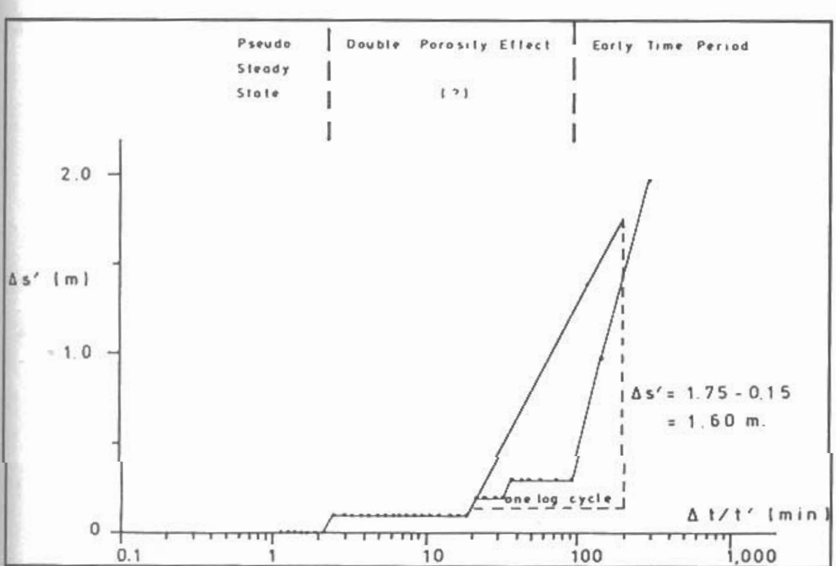


Fig. 5c: Semilog plot of recovery test data of wll G-4

Fig. 6a: Semilog plot of pumping test data of wll G-27

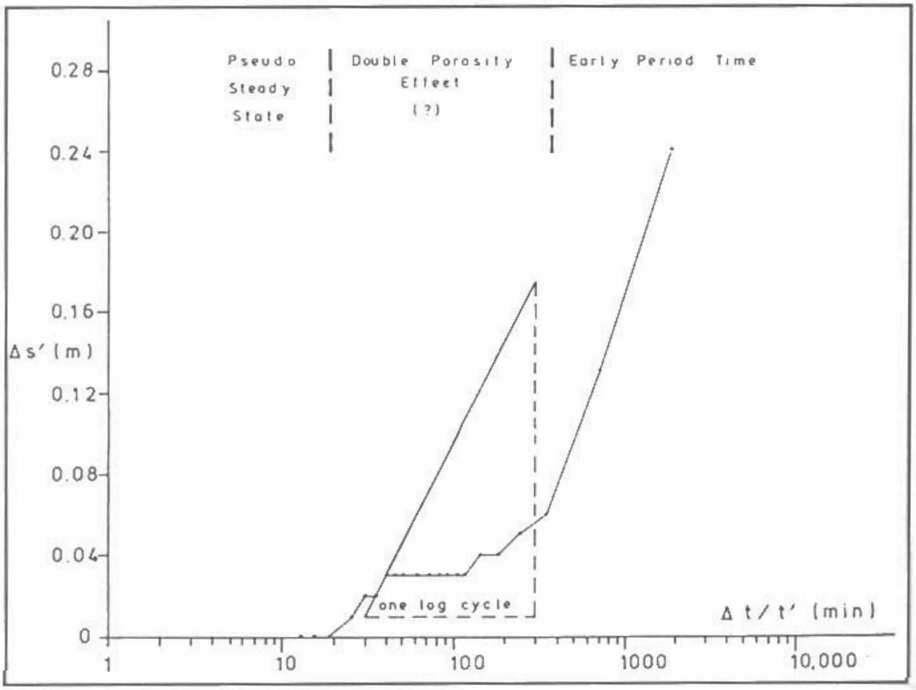


Fig. 6b: Semilog plot of recovery test data of wll G-27

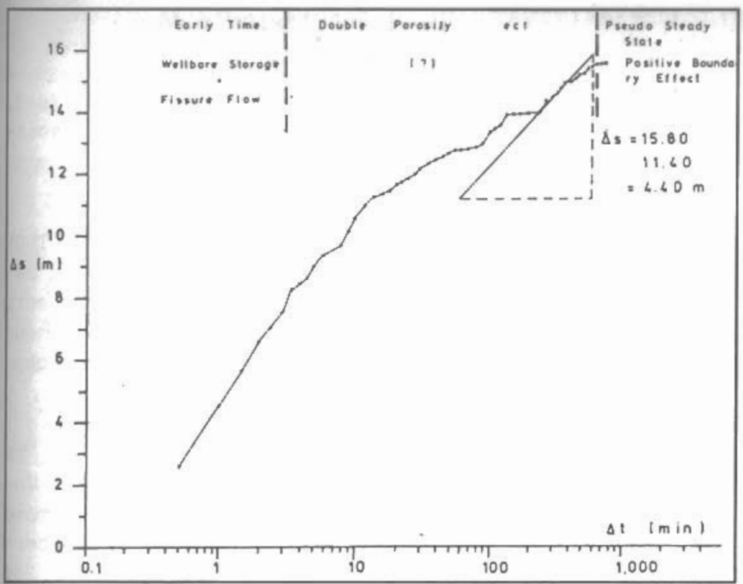


Fig. 7a: Semilog plot of pumping test data of well G-5

CONCLUSIONS

1. The thick bedded Filiatra fractured and karstified Eocene limestone horst-anticline has a thin layer of fresh groundwater which has been tapped by five boreholes.

2. By assuming the double porosity approach for fractured rock reservoirs and by assuming Darcian flow to the flow test data obtained from five produ-ction wells sunk in Filiatra unconfined limestones, the hydraulic parameters for each well are thus calculated.

3. The various hydraulic parameters of each well as calculated are as follows:

(a) For well G-2, transmissivity, T = 0.27×10^{-3} to 0.65×10^{-3} m^2/sec, while its specific capacity 0.3×10^{-1} m^2/day.

(b) For well G-9, T = 0.13×10^{-1} m^2/sec and the specific capacity 0.61×10^{-4} m^2/day.

(c) For well G-4, T = 0.10×10^{-2} to 0.08×10^{-2} m^2/sec, whereas the specific capacity is 0.98×10^{-2} m^2/day. The relation between yield and drawdown is expressed by the equation $\Delta Q = 19.7\Delta s$.

(d) For well G-27, T = 0..10×10^{-1} to 0.35×10^{-1} m^2/s, and its specific capacity

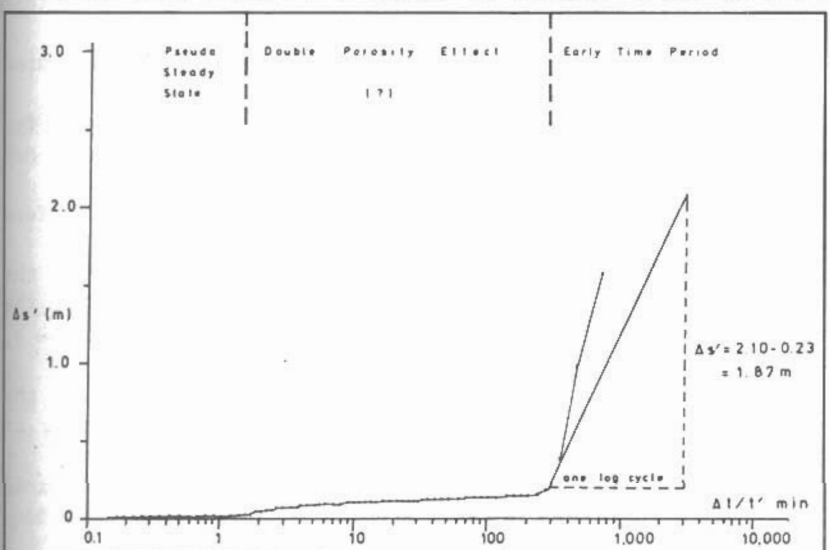


Fig. 7b: Semilog plot of recovery test data of well G-5

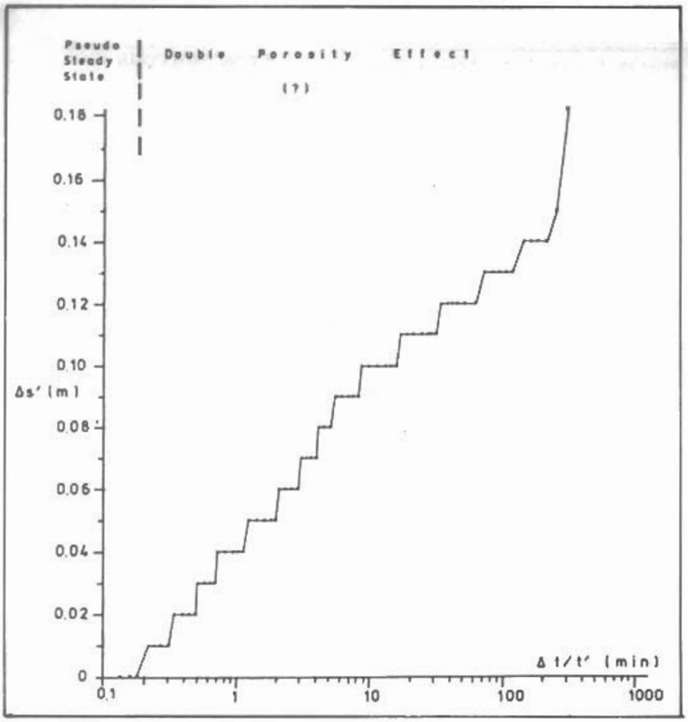


Fig. 7c: Semilog plot of recovery test data of well G-5

$= 0.16x10^{-3}$ m_2/day.

(e) For well G-5, T = $0.29x10^{-3}$ to $0.68x10^{-3}$ m^2/sec, while its specific capacity $0.26x10^{-1}$ m^2/day.

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