ANTE ŠARIN, STJEPAN GALOVIĆ and
AHMED ABDEL-WARITH

CONTRIBUTION TO THE HYDROGEOLOGY OF THE AREA EAST OF ABU ZAABAL, EGYPT

With 1 text-figure and 6 plates

Several partial aquifer tests were carried out while performing 12 production wells east of Abu Zaabal. Approximate values of ground-water hydraulic magnitudes, as well as some other hydrogeologic characteristics of the project area, are given. As ground water used in cooling processes should be injected again into the subsurface through 4 of these 12 production wells, a special discharge-recharging test was, therefore, performed.

INTRODUCTION

In 1963 the Geoistraživanja Co. (Zagreb, Yugoslavia) carried out a project that comprised drilling, completion, and testing of 12 production wells for an Egyptian company.[1] The wells are located 6–7 km eastward of Abu Zaabal, near Cairo, on the western boundary of the Eastern Desert.

Ground water is to be pumped from 8 discharging wells, then conveyed trough the plant for the purpose of cooling and, finally, injected into the subsurface through 4 recharging wells. This circular system was designed in order to preserve the limited ground-water reserves and to cut down the expenses for the disposal of the already used water. The former reason is very important especially in this region where no substantial ground water is to be unnecessarily lost.

Some of the project performance data and conclusions, presented to the investor in a comprehensive technical report, are listed in this paper. Full attention has been paid to ground-water problems. Wishing also to give, at least, a shortened general stratigraphic and structural basis of the hydrogeology of the studied area, the authors made extensive use of some of R. Said's data and views presented in a very good and up-to-date book on the geology of Egypt.

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[1] A. Abdel-Warith is the designer of the project.

The geology of the region east of Cairo was studied, after Said, by T. Barron, N. M. Shukri, M. G. Akmal, and M. K. Ayouty (Said, 1962).

In 1959 the Geoistraživanja Co. performed a deep exploration borehole near Abu Zaabal for the Ministry of Public Works of the United Arab Republic.

In 1962 two test wells were drilled to be a basis for this project. One of them was located near production well DW-1 and the other between production wells DW-6 and DW-7. They were performed by another contractor.

The authors would like to express their appreciation to the Elsevier Publishing Co., Amsterdam, for their kind permission to make use of some of the data from R. Said's book. We wish also to thank the field manager P. Mirčetić who, as well as the other technical staff of the Geoistraživanja Co., helped with collecting the data studied. Thanks are also due to J. Grčić for some technical advices, to L. Prvanović for her linguistic help, and to A. Hinšt who drew the figures of this paper.

PROJECT PERFORMANCE DATA

All wells are located in the area of about 700 m in length and about 400 m in width, as shown in Fig. 1. Each well was dug from 0 m to 4.5 m. The reverse circulation drilling by means of a Failing-Jed rig continued from 4.5 m up to basalt. The drilling diameter was 22 in. All wells were reamed onto a diameter of 26 in up to 15–20 m below a supposed static ground-water level in the discharging wells and up to the bottom at the recharging wells.

A bridge-slotted screen ranging in length from 38 m to 52 m and ended at the bottom by a 0.6 m long concrete bottom shoe was inserted into each well. The width of the screen slots was 2 mm and screen porosity was about 16 percent. Each screen was provided with centralizers in order to prevent screen eccentricity. Screens were connected with above lying I. D. 16 in and 14 in casing in the discharging and reacharging wells, respectively. A graved envelope of a 2–5 mm grain size was constructed inside the annular space of each well. The upper part of the space was filled with coarse grained sand, it ssize ranging from 0.5 to 2 mm.

The wells were tested for 6 hours of continuous pumping at the same rate of disharge. Drawdown observations in one of the neighbouring production wells were carried out during the periods of pumping and recovery. A discharge-recharging test was performed in order to obtain approximate data for designing the number, position, and construction of the recharging wells. Water was pumped from the well DW-2 during the period of 24 hours and injected into the well DW-4.

STRATIGRAPHIC AND STRUCTURAL REVIEW

A brief outline of the stratigraphic succession will be given on the basis of the description of the geology of the Cairo-Suez District given by R. Said (1962).

Upper Eocene limestones, sandy limestones, and shale beds represent the last rock unit of the Middle Calcareous Division. The Upper Clastic Division, starting with fluviatile Oligocene sands and gravels, was marked by a regression that started as early as at the end of the middle Eocene period.

The end of the Oligocene was characterized by an intensive faulting, causing climbing and flowing of basalt over the large part of Egypt. The basalt sheet assigned to the end of the Oligocene is almost horizontal. Its thickness, at Abu Zaabal exceeding 60 m, decreases remarkably towards the east.

The land subsidence took place in lower Miocene. Marine Miocene sands with calcareous sediments were deposited unconformably over Oligocene clastic materials or the basalt sheet. Sandy sediments are predominant in the lower part of this unit while calcareous deposits occur more frequently in the upper part. The thickness of marine Miocene deposits in the vicinity of Abu Zaabal is 30 m, but it increases towards the east.

Marine Miocene deposits are overlain by an about 20 m thick bed of non-marine Miocene grits and gravel cemented with calcareous material.

Miocene sediments in this region are followed by a series of Pliocene gravels which are topped by a less than 0,5 m thick porcelaneous limestone. The recent time is represented by sand dunes and coral reefs.

If these values are to be accepted as exact, clastic deposits opened by the production wells and overlying the Oligocene basalt sheet are of the Miocene and Pliocene ages. In any case, the uppermost sand belongs to Recent sand dunes. Nowadays these dunes are the most characteristic relief feature of this area.

HYDROGEOLOGIC CONDITIONS

Water-bearing beds

As the project is based on the exploitation of ground waters occurring above the basalt sheet, the basalt represents a horizontal barrier against any vertical ground-water flow from the lower, geologically older rocks than the basalt.[2]

The aquifer contains several beds of various thickness of sand, sand mixed with gravel, clay, and sand cemented with some porous calcareous material, or clean calcareous, sometimes fossiliferous reefal deposits. The ground-water body comprising a series of these beds is 61–70 m thick (Fig. 2).

The whole complex of beds underlain by the basalt sheet and saturated with water should be considered as only one aquifer.

A tendency toward the horizontal position of sediments is visible in Fig. 3.

As there are several thin beds of clay encountered in the similar position in all wells at small distances between the wells, it is supposed that only one, if not more, of these beds are connected with its approximately horizontal corresponding equivalent. In this case, or if there are horizontally limited but large lenses of clay, artesian conditions exist in practice.

[2] This geologically older ground water was studied in the »Geoistraživanja« Technical Report writen by S. Galović in 1959 and presented to the Ministry of Public Works of the United Arab Republic.

The covering group of the impermeable beds is slightly below the static water level in the majority of the wells. Therefore, a kind of combined artesian-nonartesian conditions exist, especially in the course of pumping. Hence we named the ground-water level neither water table nor piezometric surface, but only static and/or pumping water level.

The static water level is at the depth of 31 to 48 m below the ground level and it elevates the sea level about 18–19 m (Fig. 3).

A static water-level contour map shows an unnatural distortion (Fig. 2). This could be caused by the fact that ground-water levels were observed too soon after drilling, when a great quantity of water was injected into the aquifer because of the reverse circulation method of drilling. On the contrary, two or more directions of ground-water flow might also exist. A general northeast direction of flow is already known. In addition to that, large sedimentation basins of the Cairo water-supply plant, constructed west of the factory, could behave as another source of recharge. Furthermore, there are strips of well irrigated land along the eastern and western factory fences.

As the mean water level in the 5 km distant Ismailia Canal does not exceed 13 meters, it is evident that the canal in this region is abundantly recharged by the ground water of the Eastern Desert.

Specific capacity

Specific capacities of the wells are shown in the map (Fig. 2). Test pumping was stopped a little before reaching a steady state of flow. Calculated values of specific capacities are, therefore, slightly higher than the actual ones, but the differencies are negligible in practice.

Values of the obtained specific capacities, being very similar, show an evident similarity of aquifer transmissibility over the whole area of study. Specific capacities range from 13.8 to 26.1 m^2/h.

Aquifer transmissibility

Steady flow conditions were not reached because pumping tests did not last long enough. Neverheless, we observed drawdowns in some of the neighbouring wells when the wells DW-2 and DW-4 were pumped, The pumping of each well was performed separately.

In order to utilize drawdown observations in pumped wells, measured inside the well screen, an assumed well loss was taken into consideration

(Fig. 4). Approximate coefficients of permeability thus obtained for the wells DW-2 and DW-4 are 11.1×10^{-3} and 9.8×10^{-3} m²/s, respectively.

After the stoppage of pumping, the recovery of ground-water levels was being observed in the nearest of the already completed wells (Fig. 5). The obtained curves do not show an evident straight part, which is caused by the existence of the original ground-water flow and by semi-confined conditions. The results obtained by means of steady flow solutions were utilized in order to find out at least approximate straight parts. The left parts of the time-residual drawdown curves for the wells DW-2 and DW-4 were found to satisfy the results of the distance-drawdown curves. These parts belong to the last observations.

Taking the same period of observations for the approximate straight parts of the curves of another three wells, the approximate coefficients of transmissibility, after the Jacob solution of the nonequilibrium equation, are 9.6, 9.5, 10.0, 6.9, and 5.2×10^{-3} m²/s for the wells DW-2, DW-3, DW-4, DW-7, and RW-12, respectively (Fig. 2).

All these values show the same order of magnitude satisfying the idea of a similar transmissibility of the entire area mentioned when describing specific capacities of the wells. This conclusion is also confirmed by the drilling logs where hydrogeologically similar deposits were found.

Storage coefficents

In the course of the pumping period drawdowns were observed in the well DW-3 when pumping the well DW-4 and vice versa. Approximate storage coefficients, also computed after the Jacob solution of nonequilibrium equation, are 9.5×10^{-5} and 2.6×10^{-5} for the wells DW-3 and DW-4, respectively.

As said before, drawdowns were also observed during the recovery period, when the wells DW-2, DW-3, DW-4, DW-7, and RW-12 were being tested (Fig. 6). The approximate storage coefficients, obtained by means of the Jacob method, are 5.0×10^{-5}, 9.9×10^{-5}, 4.5×10^{-5}, 5.4×10^{-5}, and 3.3×10^{-5} for the wells DW-2, DW-3, DW-4, DW-7, and RW-12, respectively.

The last observations of water level recovery were used for computations in the same way as it was done while studying the transmissibility of the aquifer.

The obtained results are also of an approximate value for the same reasons as mentioned before. The same order of the magnitude of the results obtained show again that similar hydrogeologic conditions prevail all over the project area. The nonexistence of any water-table conditions is also proved by the order of the magnitude of the storage coefficients obtained.

DISCHARGE-RECHARGING TEST

The well DW-4 was continuously recharged with water from the well DW-2 for the period of 24 hours. The test was carried out in three steps, each lasting 8 hours. There was no stoppage between the steps.

The specific capacity of a well represents pumping (discharging) characteristics of the well. We named its recharging equivalent, i. e., the ratio between the rate of recharge and the ground-water level increment in a recharged well, the specific recharge capacity of the well, or $q_r = Q_r / \Delta h$. If a discharge-recharging system is, such as described here, then $q_r = Q_r$ $(\Delta h + s)$, where s is a drawdown in the recharged well when there is no recharging but only pumping. In this case $q_r = Q_r$ $(\Delta h_4 + s_4)$. The symbols of this term are identified in Fig. 7.

Supposing the change of drawdown approximately with the first power of discharge rate, corresponding values of drawdown s_4 were computed on the basis of the drawdown in the well DW-4, which was 0.30 m when the well DW-2 was pumped at the discharge rate of 133.70 m³/h, as follows:

Step	Q_r (m³/h)	s_4 (m)
I	66.4	about 0.15
II	87.0	about 0.20
III	115.6	about 0.26

As the increments Δh_4 for steps I, II, and III are 3.95 m, 4.49 m, and 6.34 m, the specific recharge capacities of the well DW-4 are approximately 16.2, 18.5 and 17.5 m²/h, respectively.

These values are approximate for the same reason as the previous ones, namely, a full steady state of ground-water flow was not reached after the completion of each of the steps. The differences between the data obtained and the actual ones should be neglected in practice.

CHEMICAL COMPOSITION OF GROUND WATER

Two samples of ground water were picked out for chemical analysis, one from the test well No. 1 and the other from the test well No. 2. The analyzed waters contain the following main components:

	Test well No. 1		Test well No. 2	
	ppm	meq/l in percents	ppm	meq/l in percents
Total salinity (including bicarbonates)	2900	—	4197	—
Chlorides	1034	64	1647	58
Sulphates	161	12	395	7
Carbonates (including bicarbonates)	590	24	595	35
Calcium	99	13	187	10
Magnesium	49	10	84	8
Sodium and potassium	944	77	1266	82

The carbonates, bicarbonates, and sodium with potassium were not measured but computed.

The total salinity of these waters shows an essential difference, although the milligram equivalents per liter expressed in percents indicate that both belong to the same kind: sodium-chloride-carbonate water, and both should originate from the same source. It is supposed that the differencies between the total salt contents could be effected by a certain refreshing of ground water, as fresh irrigation water infiltrates the subsurface in this part of the project area. Nevertheless, it is important to mention that the latter analyses of the water from the production wells DW-1 and DW-6 give similar results. The total salts dissolved (excluding bicarbonates) in the water from the wells DW-1 and DW-6 are 2584 ppm and 4320 ppm, respectively. The percentage ratio of the milligram equivalents for the latter analyses cannot be found since all the components were not analyzed.

SUMMARY

A project for the construction of 12 production wells for cooling purposes was performed by the Geoistraživanja Co. (Zagreb, Yugoslavia) in 1963. Eight wells were performed for pumping of ground water, and four for injecting the used water again into the subsurface. The wells occupy an area measuring about 700 m by 400 m, 6–7 km east of Abu Zaabal, in the Egyptian Eastern Desert.

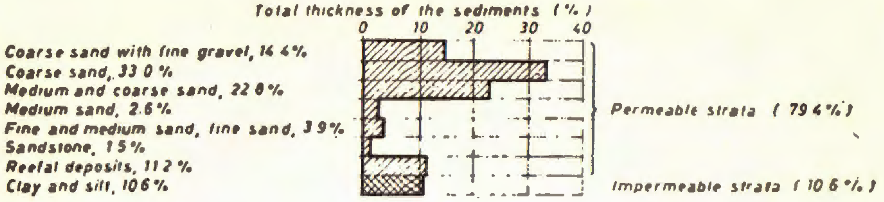

Fig. 1. Histogram of the mean lithologic section of the aquifer. Sl. 1. Srednji dijagram učestalosti sedimenata vodonosnog sloja

Reverse circulation drilling method was applied succesfully. The wells are of a nearly completely penetrating type, the average depth of which is about 106 m, and the average lenght of an I. D. 10 in bridge-slotted screen is about 47 m. The diameter of the screened part of the well is 22 in at the discharging wells and 26 in at the recharging wells. After the completion, each well was separately test pumped for 6 hours.

The authors computed and described hydrogeologic magnitudes and conditions on the basis of the drilling logs and the mentioned aquifer tests. The stratigraphic and structural description of the area of study given in the paper is based on a new book on the geology of Egypt written by R. Said (1962).

Special artesian and water-table conditions exist in non-pumping stage. A kind of semi-confined conditions exists in pumping stage because of the existence of several large clay interbeds in the upper part of the aquifer that behave as semi-impermeable confining beds and allow some leakage.

On the average, the non-pumping ground-water level is 18–19 m above the sea level and from about 31 to about 48 m under the ground level.

A general eastward direction of the ground-water flow is registered. There is a probability of the existence of two more local sources of the ground-water recharge.

The mean specific capacity for all the 12 production wells is about 22 m^2/h.

The mean coefficient of transmissibility for the production wells DW-2, DW-3, DW-4, DW-7, and RW-12 is about 9×10^{-3} m^2/s. This value refers to the results obtained on the basis of both steady and non-steady flow solutions.

The mean storage coefficient for the production wells DW-2, DW-3, DW-4, DW-7, and RW-12, computed on the basis of drawdown and recovery tests, is about 5×10^{-5}.

A discharge-reacharging test has also been carried out in order to obtain basic data for the designing of the recharging well system. The water was pumped from the well DW-2 and injected into the well DW-4 continuously during the period of 24 hours. The so-called specific recharge capacity of the well DW-4 is about 17 m^2/h.

It is necessary to point out that all the obtained data on ground water hydraulics are of an approximate exactness, for neither full steady nor non-steady conditions existed during the performance of the tests, but the differences between the obtained values and the actual ones cannot be of any importance in practice.

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Geoistraživanja Co., Zagreb, Kupska 2
Cairo University, Egypt

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A. ŠARIN, S. GALOVIĆ i A. ABDEL-WARITH

PRILOG HIDROGEOLOGIJI PODRUČJA ISTOČNO OD ABU ZAABALA, EGIPAT

Poduzeće Geoistraživanja iz Zagreba izradilo je u toku 1963. god. za jedno egipatsko poduzeće 12 bunara za opskrbu tvornice podzemnom vodom za hlađenje postrojenja. Bunari su međusobno udaljeni 150–300 m a nalaze se u Istočnoj (Arapskoj) pustinji, nekoliko kilometara od njenog zapadnog ruba.

Iz osam bunara voda se crpi, a kroz preostala četiri voda se ponovo vraća u podzemlje uglavnom zbog razloga da se spriječi trošenje oskudnih rezervi podzemne vode.

Bunari su prosječne dubine oko 106 m, promjera bušenja u sektoru filtra 22–26" a s prosječno 47 m dugim mostićavim filtrom čiji je promjer 10". Između filtra i stijenke bunara zasut je prosijani šljunak.

Stratigrafsko tektonski podaci, izneseni u ovom radu, crpeni su iz vrlo dobre, nedavno publicirane knjige o geologiji Egipta (Said 1962).

Najstarija stijena, nabušena bunarima, je oligocenski bazalt. Gotovo horizontalno položena bazaltna ploča proteže se na ogromnom prostranstvu u sjevernom Egiptu. Na bazaltu su taložene miocenske naslage i to najprije marinski pijesci s ulošcima vapnovitih grebenskih naslaga a na njima slatkovodni šljunak vezan vapnovitom supstancom. Vjerojatno je nabušeno i nešto pliocenskih šljunkovitih naslaga. Na samom vrhu su holocenske eolske naslage, čiji se morfološki oblici vrlo izrazito ističu u ovom području.

Nekoliko desetaka metara debela i vrlo prostrana bazaltna ploča predstavlja barijeru podzemnoj vodi koja se nalazi pod i nad bazaltom. Ova potonja, koja se opisivanim bunarima eksploatira, predstavlja praktično jedan vodonosni horizont, iako je samo vodno tijelo u gornjim dijelovima odvojeno 1–3 m debelim ulošcima glinovitih sedimenata. Ovako tanki slojevi glinovitih naslaga predstavljaju polupropusne tvorevine pa se podzemna voda nalazi pod izvjesnim semi-arteškim uvjetima. Vodonosne naslage debele su 61–70 m a nivo podzemne vode je 31–47 m pod površinom terena.

Otprije je poznato da podzemna voda uglavnom dotječe s jugoistoka iz područja između doline Nila i Sueskog zaljeva. To dokazuje i nivo podzemne vode tretiranog područja, koji je za 5–6 m viši od srednjeg vodostaja u nekoliko kilometara udaljenom Ismailia kanalu, najistočnijem od glavnih kanala Delte Nila. No, karta nivoa podzemne vode pokazuje mogućnost postojanja dvaju ili više izvora napajanja. Anomalije, koje se vide na ovoj karti, mogle su biti uzrokovane i napajanjem podzemlja za vrijeme bušenja bunara, pošto je ono izvođeno s reversnim ispiranjem kod kojega se ogromna količina vode infiltrira u izbušene naslage.

Svaki bunar je šest sati pokusno crpen. Sniženje nivoa ni u crpnom ni u susjednim bunarima, koji su tom prilikom poslužili kao pijezometarske bušotine, nije se za to vrijeme stabiliziralo, tj. nije nastupilo stacionarno protjecanje. Sve odredbe hidrogeoloških parametara – kao što su specifični kapacitet bunara, specifični protok, koeficijent uskladištenja, specifični naljevni kapacitet bunara – bile su približne vrijednosti, jer zbog prirodnog podzemnog pritjecanja nisu mogli biti uspostavljeni nestacionarni uvjeti protjecanja (karakteristični za bazenski tip rezervoara) a zbog kratkotrajnog crpenja nisu uspostavljeni stacionarni uvjeti (koji trebaju postojati kod protočnog tipa rezervoara). No, izračunate vrijednosti se zanemarljivo razlikuju od stvarnih veličina.

Specifična izdašnost bunara je izračunata za sve bunare. Ona varira od 13,8 do 26,0 m^2/h, sa srednjom vrijednošću od oko 22 m^2/h.

Specifični protok (coefficient of transmissibility) određen je pomoću rješenja za stacionarne i nestacionarne uvjete za bunare br. DW-2, DW-3, DW-4, DW-7 i RW-12. Prosječni specifični protok iznosi oko 9×10^{-3} m^2/sec, dok pojedinačni rezultati variraju u rasponu od 5,2 do $11,1 \times 10^{-3}$ m^2/sec.

Koeficijent uskladištenja (storage coefficient) određen je na bazi mjerenja u fazi crpenja i vraćanja nivoa za bunare DW-2, DW-3, DW-4, DW-7 i RW-12. Veličina ovog koeficijenta, koja varira od 2,6 do $9,9 \times 10^{-5}$, ili koja u prosjeku iznosi oko 5×10^{-5}, pokazuje da je vodonosni horizont arteškog, odnosno semi-arteškog, a nipošto ne slobodnog tipa.

24-satno pokusno napajanje bunara br. DW-4 vodom koja je istovremeno crpena iz bunara br. DW-2 pokazalo je da specifični naljevni kapacitet bunara (kako smo nazvali kod napajajućeg bunara ekvivalentni pojam specifičnom kapacitetu kod običnog, depresionog bunara) br. DW-4 približno iznosi 17 m^2/h.

Kemijski sastav podzemne vode utvrđen je na uzorcima izvađenim iz dviju istražnih bušotina koje su bile izbušene prije izrade bunara. Procentualni odnosi miligram-ekvivalenata pokazuju da oba uzorka pripadaju istom tipu voda: natrijsko klorido-karbonatskoj vodi, ali voda u bušotini br. 2 ima za oko 45 % veći ukupni sadržaj otopljenih soli od vode u bušotini br. 1. Razlog ovoj pojavi može biti, možda, oslađenje podzemne vode poniranjem slatke površinske vode, jer se u blizini bušotine br. 1 zemljište intenzivno navodnjava.

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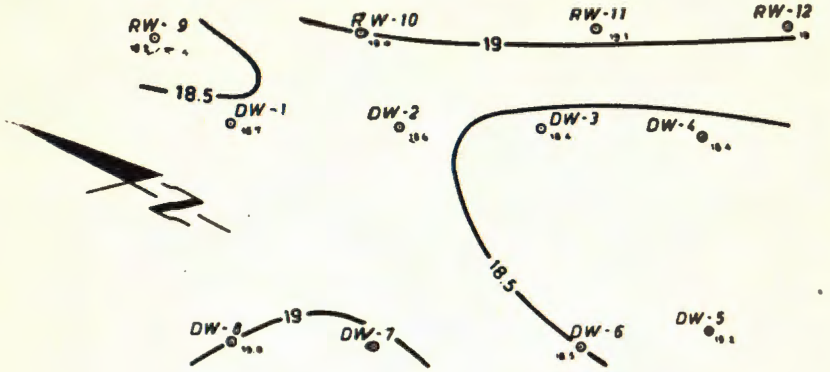
»Geoistraživanja«, Zagreb, Kupska 2
Univerzitet u Kairu

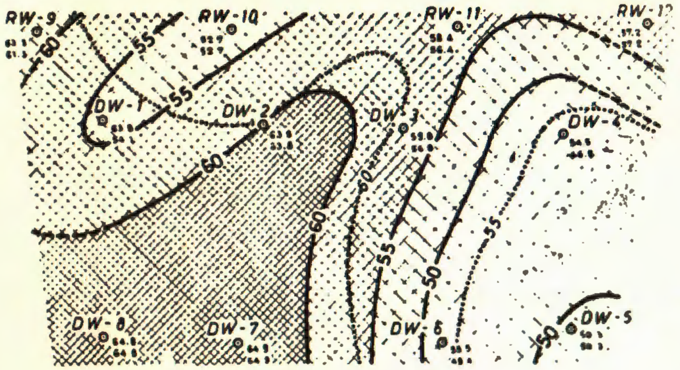
APPROXIMATE CONTOUR MAP OF DISTORTED STATIC WATER LEVELS
(For April - June 1963)



Elevation of the static ground water level (m)

Static water levels were measured as follows
DW-1, DW-2, DW-3 · 14 4.1963 ; DW-4 : 10 4.1963,
DW-5 : 13 4.1963; DW-6 : 18.5 1963; DW-7 : 7 5 1963;
DW-8 : 2 5 1963 ; RW-9 : 4 6 1963 ; RW-10 : 6 6 1963,
RW-11 : 13 6 1963; RW-12 : 19 6 196

ISOPACH MAP OF THE AQUIFER



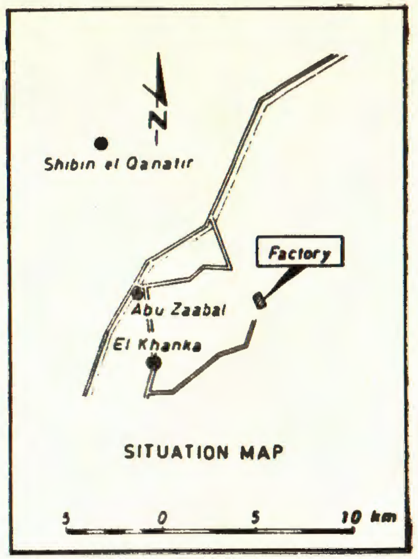
Thickness of the permeable strata (m)
Thickness of the high permeable strata (m)

Isopach contour line of the permeable strata saturated with ground water (m)

Isopach contour line of the high permeable strata (i permeable strata excluding fine sand and fine sand with medium sand) (m)

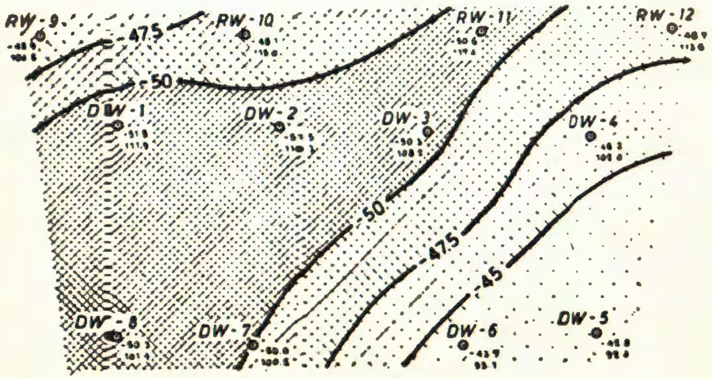
Thickness of the high permeable strata (m)

▨	*from 45 to 50*	▨	*from 55 to 60*
▨	*from 50 to 55*	▨	*from 60 to 65*



SITUATION MAP

CONTOUR MAP ON THE TOP OF BASALT

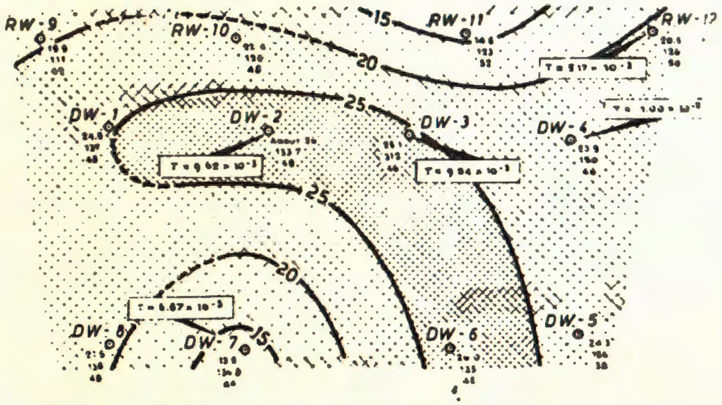


Elevation of the top of basalt (m)
Depth (from surface) to the top of basalt (m)

Elevations of the top of basalt (m)

▨	*from -42 5 to -45*	▨	*from -475 to -50*
▨	*from -45 to -475*	▨	*from -50 to -52 5*

MAP OF WELL SPECIFIC CAPACITY



Specific capacity of the production well (m³/h)
Test pumping discharge (m³/h)
Lenght of the screen (m)

T · Approximate coefficient of transmissibility (m²/ sec)

Specific capacities of the production wells (m³/h)

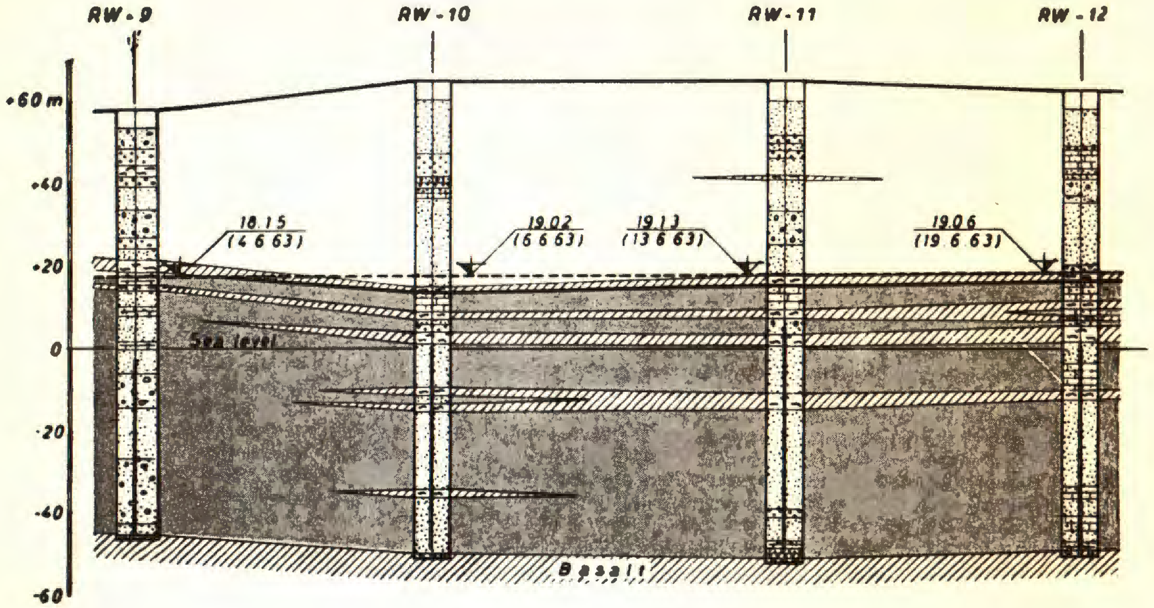
▨	*from 10 to 15*	▨	*from 20 to 25*
▨	*from 15 to 20*	▨	*from 25 to 30*

- ⊙ *Production well*
- *DW Discharging well*
- *RW Recharging well*

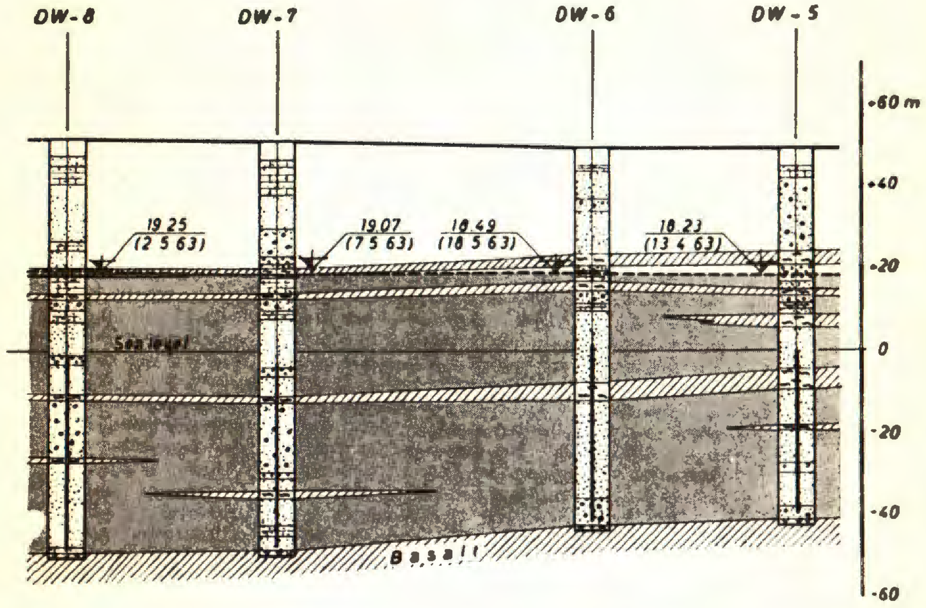
100 0 100 200 300 400 m

PLATE – TABLA II

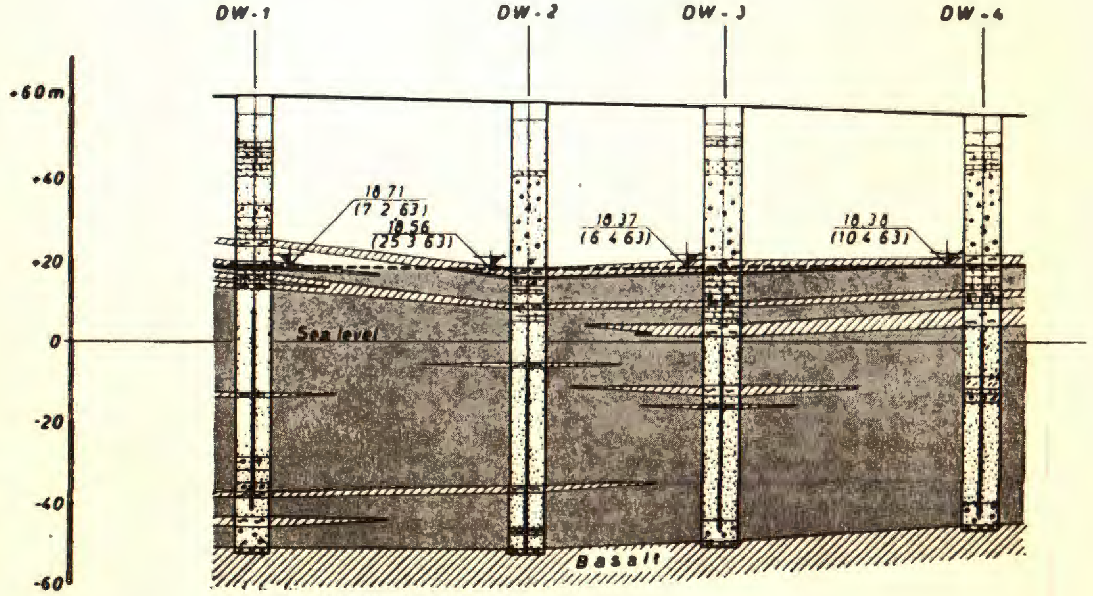
CROSS SECTION 1



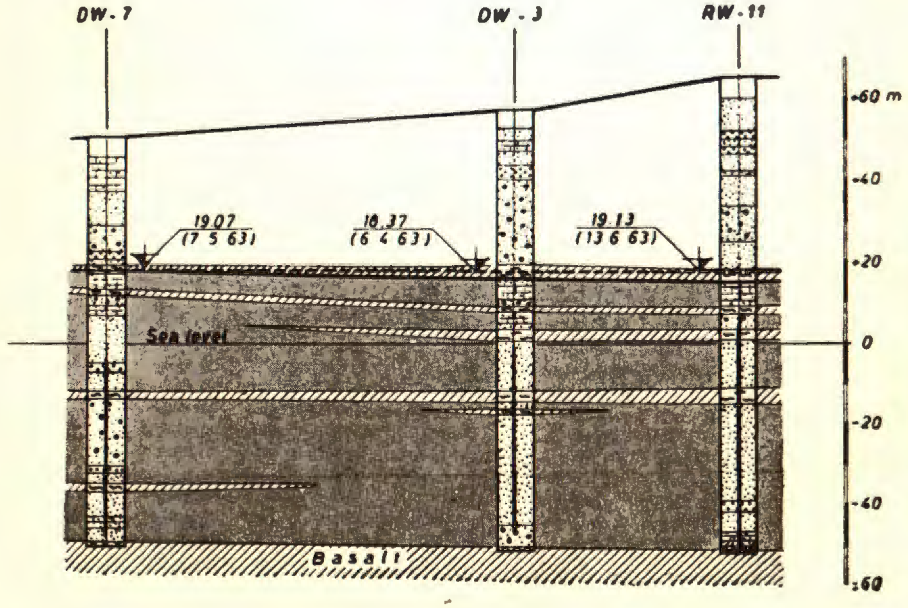
CROSS SECTION 3



CROSS SECTION 2



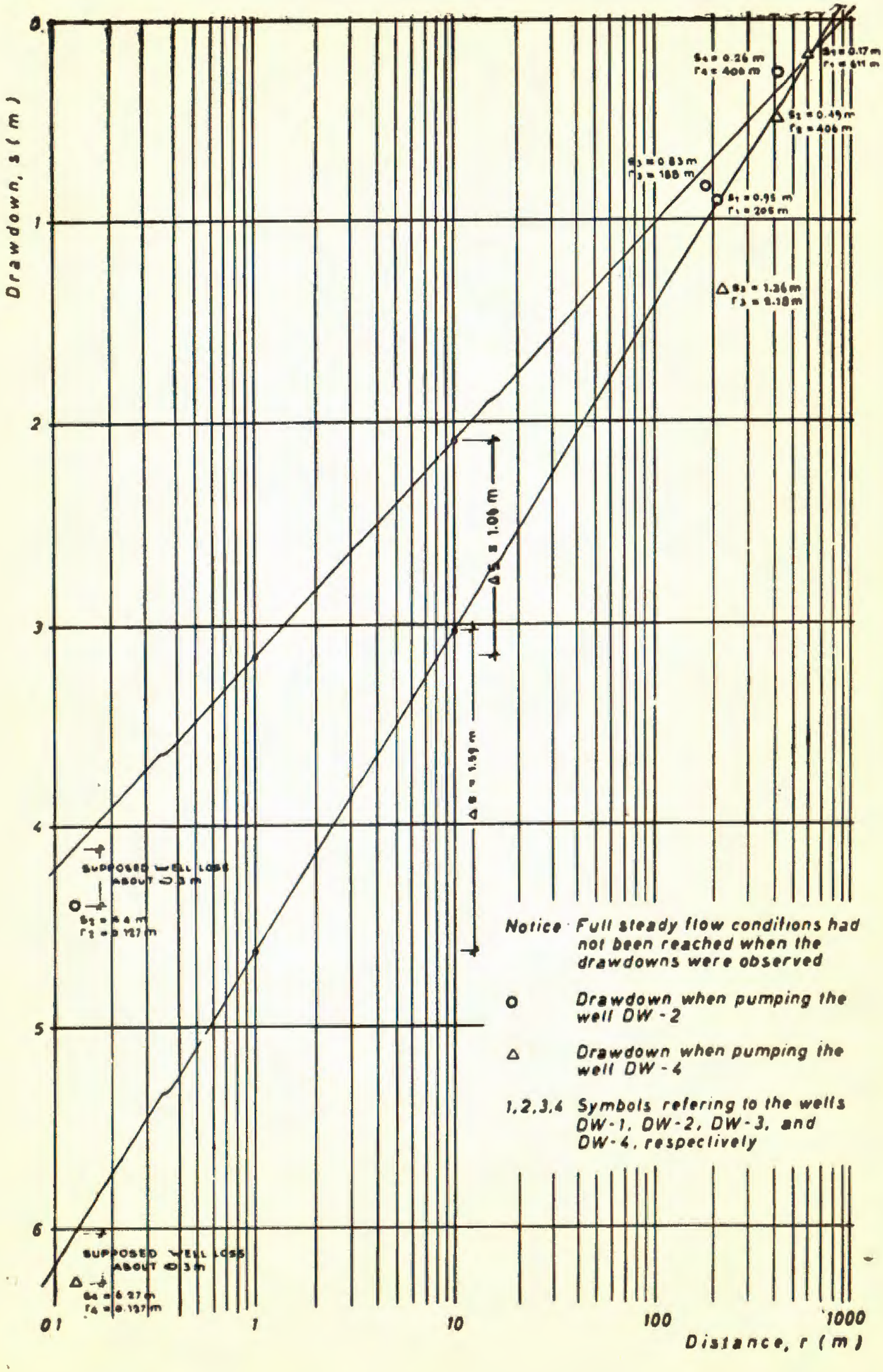
CROSS SECTION 4

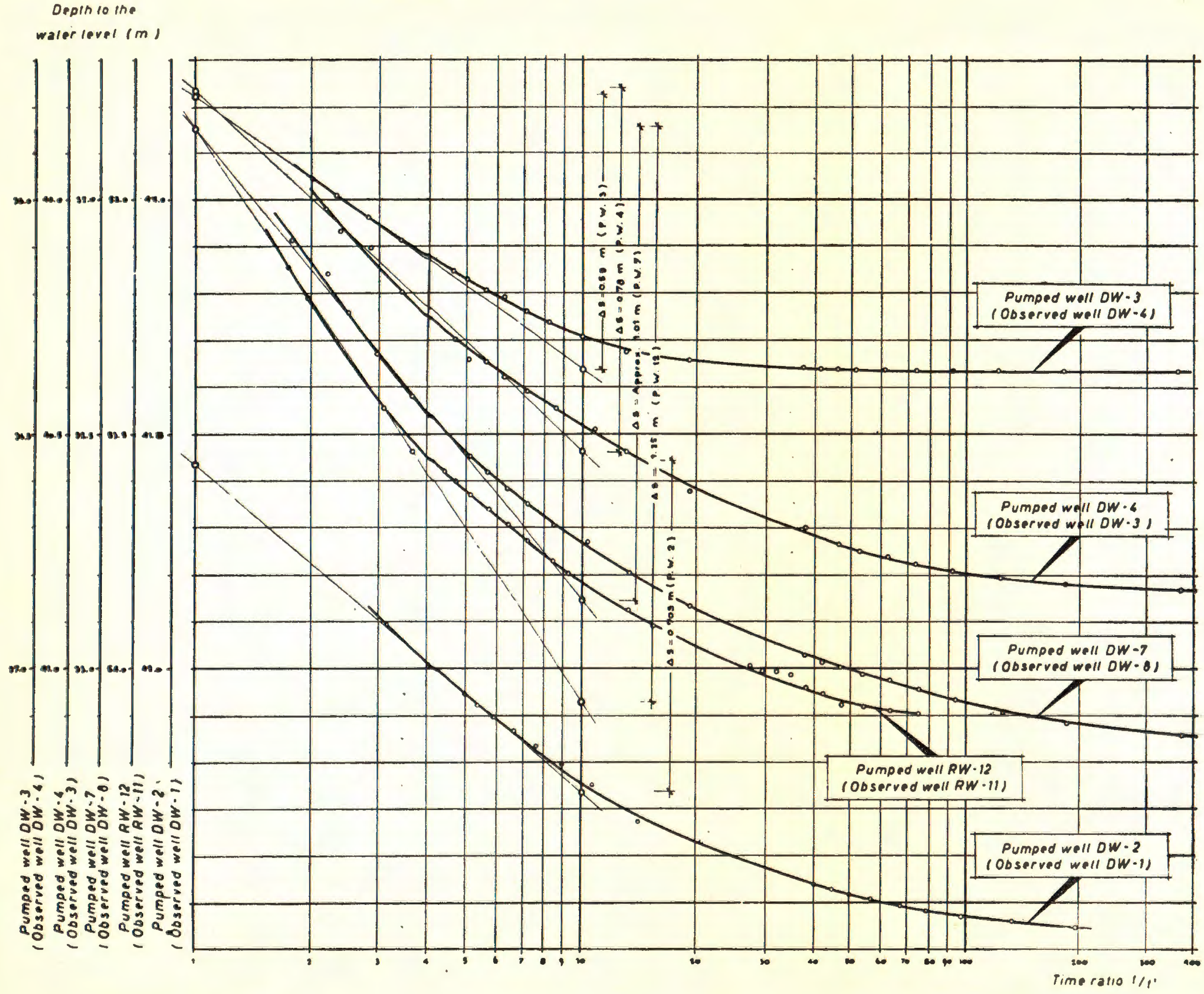


REFERENCE

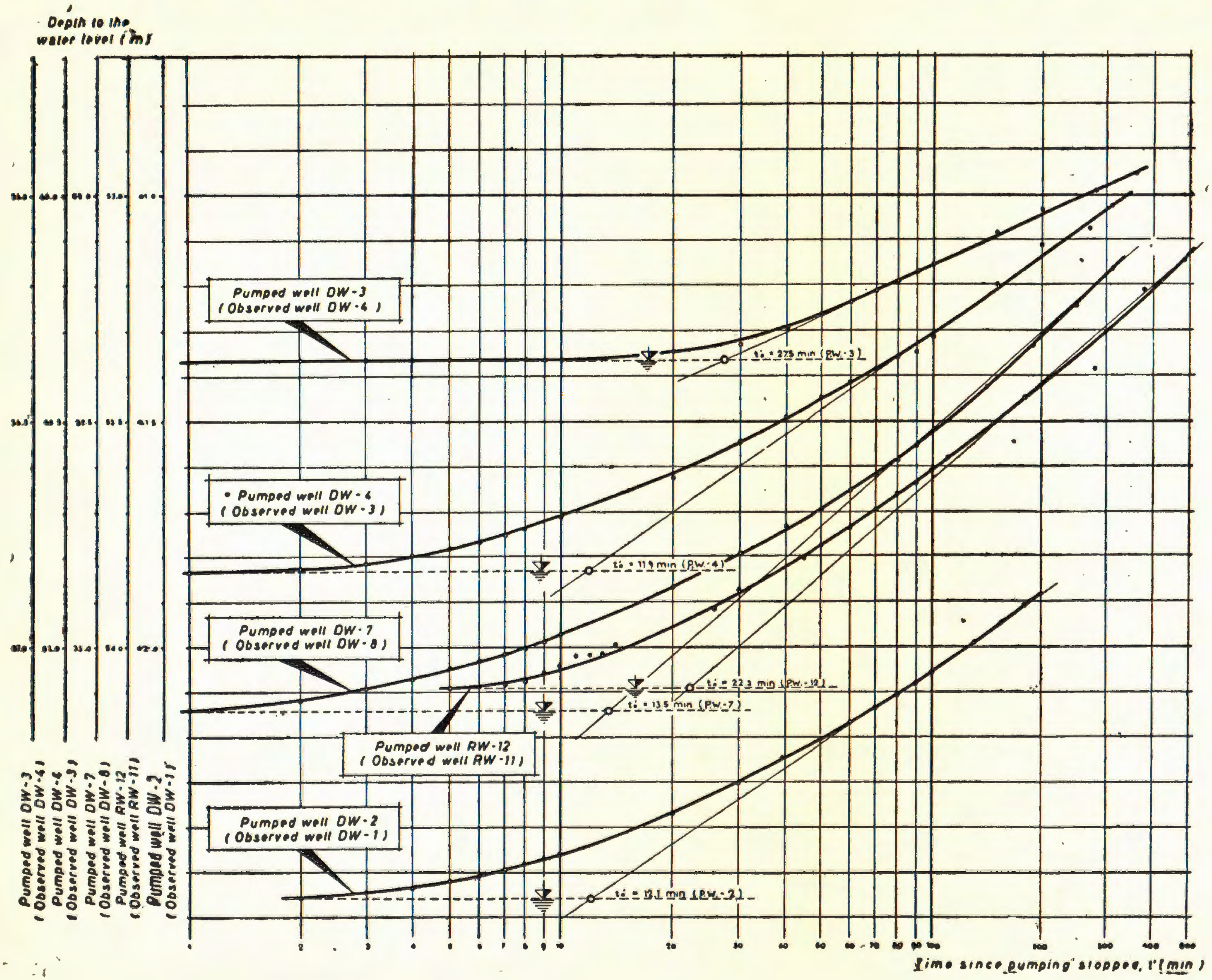
⁘ Gravel
░ Sand (coarse, medium & fine sand)
░ Sandstone
▦ Reefal deposits (sand, fine gravel cemented with organic limestone)
} Permeable strata
▨ Silt
▭ Clay
▭ Basalt
} Impermeable strata
▨ Impermeable strata
▓ Water bearing strata
▽--- Static water level (water table or piezometric surface)
18 35 Elevation of the static water level
4 6 63 Observation date
DW Discharging well
RW Recharging well
│ Casing
┃ Screen
— Supposed top of the artesian aquifer

100 0 100 200 300 m

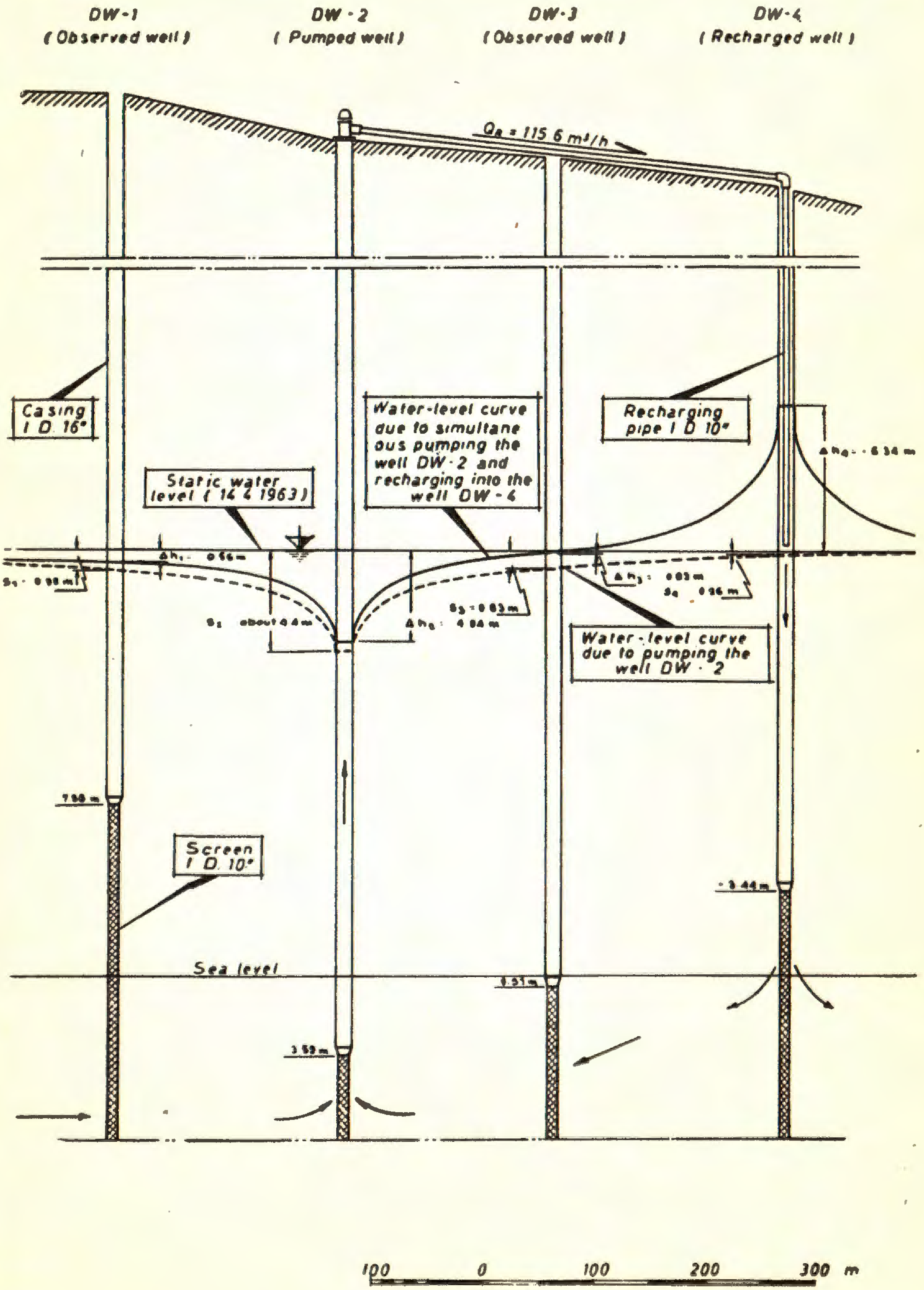

Drawdown, s (m)
0
1
2
3
4
5
6
Distance, r (m)
01
1
10
100
1000
s_4 = 0.26 m
r_4 = 400 m
s_1 = 0.17 m
r_1 = 611 m
s_2 = 0.49 m
r_2 = 406 m
s_3 = 0.83 m
r_3 = 188 m
s_1 = 0.95 m
r_1 = 206 m
s_3 = 1.26 m
r_3 = 9.18 m
Δs = 1.06 m
Δs = 1.59 m
SUPPOSED WELL LOSS ABOUT 0.3 m
s_2 = 4.4 m
r_2 = 0.127 m
SUPPOSED WELL LOSS ABOUT 0.3 m
s_4 = 6.27 m
r_4 = 0.127 m
Notice · Full steady flow conditions had not been reached when the drawdowns were observed
○ Drawdown when pumping the well DW - 2
Δ Drawdown when pumping the well DW - 4
1, 2, 3, 4 Symbols refering to the wells DW-1, DW-2, DW-3, and DW-4, respectively



p w	*Pumped well*
DW	*Discharging well*
RW	*Recharging well*
t	*time since pumping started*
t'	*time since pumping stopped*



p.w	Pumped well
DW	Discharging well
RW	Recharging well
- - - -	Pumping water levels in the observed wells when pumping stopped


DW-1
(Observed well)
DW-2
(Pumped well)
DW-3
(Observed well)
DW-4
(Recharged well)
Q4 = 115.6 m³/h
Casing I.D. 16"
Water-level curve due to simultaneous pumping the well DW-2 and recharging into the well DW-4
Recharging pipe I.D. 10"
Δh4 = - 6.34 m
Static water level (14.4.1963)
Δh1 = 0.56 m
S1 = 0.98 m
S2 about 4.4 m
S3 = 0.83 m
Δh2 = 4.04 m
Δh3 = 0.03 m
S4 0.26 m
Water-level curve due to pumping the well DW-2
7.98 m
Screen I.D. 10"
- 3.44 m
Sea level
0.51 m
3.59 m
100
0
100
200
300 m