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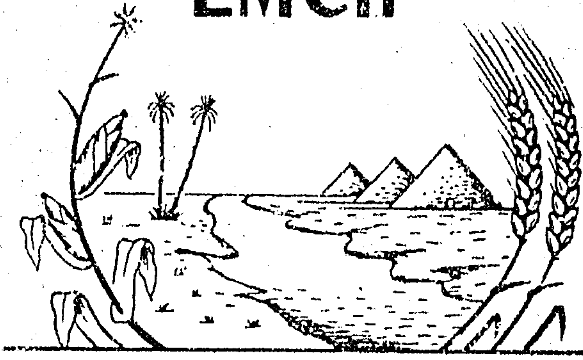

المشروع المصرى لتحسين محاصيل الحبوب الرئيسية

EGYPTIAN MAJOR CEREALS IMPROVEMENT PROJECT

RESEARCH - EXTENSION

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RESEARCH REPORT

EVALUATION OF THE DRAINAGE SYSTEM AT EL-GEMMEIZA RESEARCH/EXTENSION CENTER

BY

DR. SOLIMAN EL-HAMCHARY AND DR. HAMED HASSEN ALI

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EVALUATION OF THE DRAINAGE SYSTEM AT EL-GEMMEIZA RESEARCH/EXTENSION CENTER

by

Dr. Soliman El-Hamchary and Dr. Hamed Hassan Ali
Soil and Water Research Institute
Field Drainage Research Department

Content

Evaluation of the Drainage System at El-Gemmeiza Research/Extension Center

by

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1. Introduction

The main objectives of field drainage are to promote favourable soil-water-air relations. A distinction can be made between soil drainage and crop drainage.

Soil drainage is required to maintain soil structure and soil nitrogen supply in states favourable to plant growth. It is also required to maintain soil traffic and workability; i.e. plowing, cultivating, and decrease puddling by livestock. For these reasons the benefits of soil drainage have an indirect but important effect on the productivity of the land. Crop drainage is required to obtain a well aerated root zone in which the plant can grow and flourish to produce maximum yield.

Therefore, it is of great importance to evaluate and check the drainage system which was established in the fields belonging to EMCIP at El-Gemmeiza Farm and in addition to provide high quality data about the hydraulic properties of the area.

2. Materials and Methods

2.1. The selected site:

Evaluation of the drainage system was carried out at the site of about 321 Feddans, (one feddan = 4200 m^2), located at the experimental farm of, El Gemmeiza in the Nile Delta of Egypt which was consigned for use by EMCIP. The soil profile is a relatively deep alluvium with a clay texture to the depth of two meters according to the parameters described by Richards (1954). The particle size distribution is presented in Table (1).

2.2. Drainage System:

2.2.1. Spacing design: The drainage field was established 5 years ago as shown in fig (1). The laterals are composed of cement pipes of 10 cm. diameter. The subsurface drainage laterals have a length of approximately 125.0 m and an

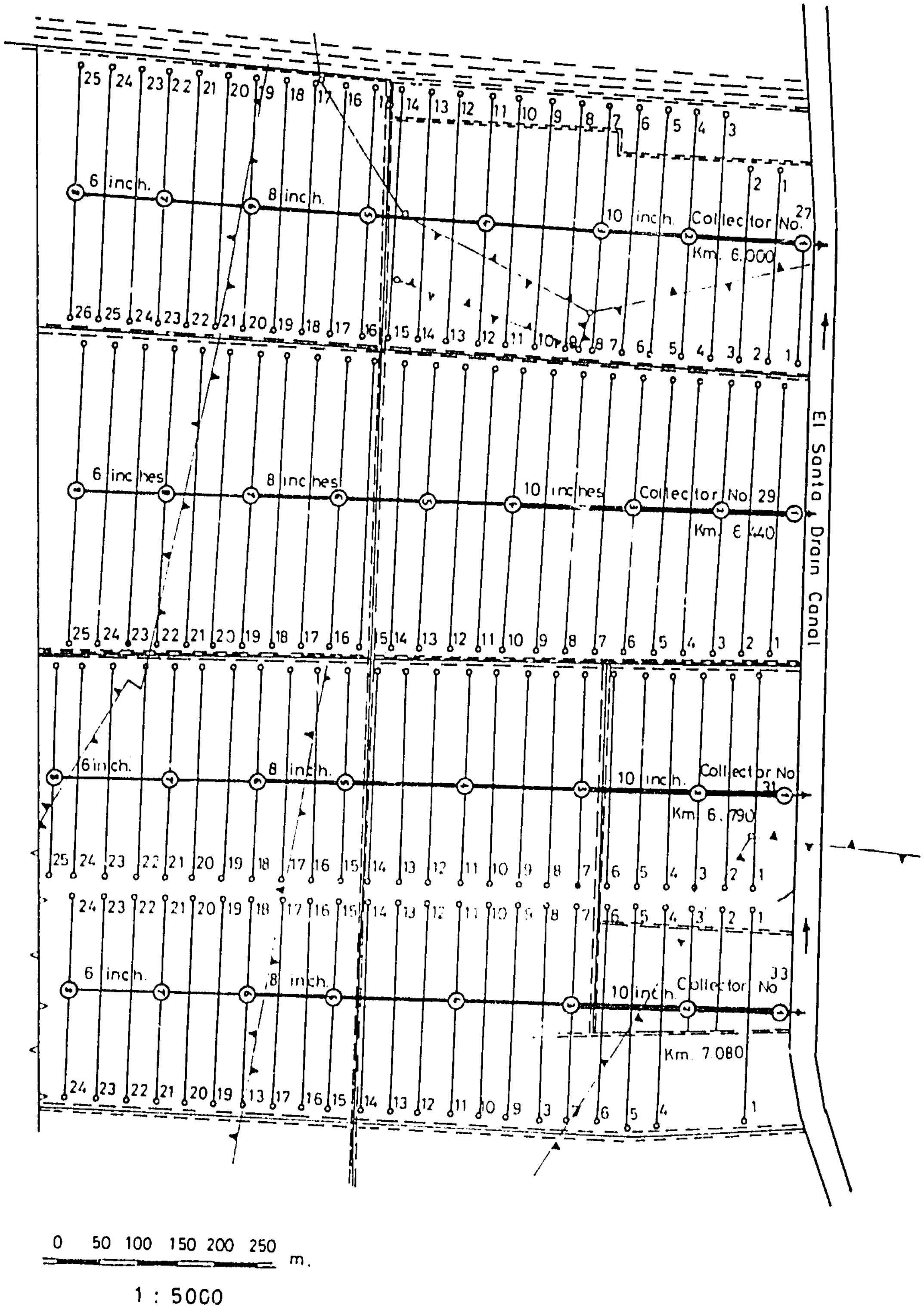

Fig. (1) : Lay-out of tile drains at El-Gemmeiza Farm.

Table (1)

Some physical properties of soils on EMCIP Research/Extension Center, El Gemmeiza Farm, ARE.

Depth cm	Bulk * density 9/cm^3	Particle size distribution**			Moisture content %***		
		Clay %	silt %	sand %	PF 0	PF 2.0	PF 4.2
0- 10	1.27	38.34	29.69	31.97	76.82	44.04	22.35
10- 20	1.34	37.71	29.66	32.63	76.14	44.46	27.05
20- 40	1.34	38.75	29.46	31.79	76.78	42.64	25.19
40- 60	1.32	38.24	31.07	30.69	74.12	42.84	26.89
60- 80	1.32	37.89	31.32	30.79	73.72	42.11	25.19
80-100	1.32	37.54	31.95	30.51	74.61	42.54	25.89
100-120	1.30	37.15	31.88	30.97	70.49	42.75	25.15

* average of 12 replicates

** clay + silt + sand = 100 %
average of 6 replicates

*** average of 3 replicates

average depth 1.25 m. Lateral drain spacing is 40.0 m according to the formula of Hoodhoudt (1940). All laterals are with unblocked joints between the individual tile pipes and without filter envelope. All laterals are collected in collectors of 0.25 m. Junctions between laterals and collector pipes were made by an inspection chamber. The distance between two chambers is about 120 to 160 m. A set of groundwater pipes, i.e. piezometers, were installed along a line perpendicular to the laterals. The piezometer installations were at ¼, ½, 3/4 drain length, each line consisting of a piezometer, just outside the trench (40 cm from the drain center), at 1/8 drain spacing and at mid-spacing. Intensive periods after irrigation were chosen and daily observations were carried out to study the hydrological characteristics under investigations. The drain outflows using volumetric methods was measured simultaneously with the water table levels. The in-site hydraulic conductivity has been determined by the auger hole method according to van Beers (1958). The moisture-holding capacity was estimated from PF-curves derived from soil core samples.

2.3. Data Processing:

The obtained hydrological data were processed by using steady and non steady state solutions. The field observations of discharge rates and water table heights were processed by converting their values into m and mm per day respectively. The converted values were plotted versus time and a best fit line was drawn. Then the q_o and h_o values were plotted versus time on a semi-log paper to obtain q_t and h_t. Due to the absence of drain discharge for Laterals No. (7) and (8), q_t was calculated by the equation:

$$q_t = \frac{2af}{\pi} h_t \qquad (1)$$

where

q_t = drainage rate after a certain time "t" (m/day)

a = drainage intensity factor "a" (days)

f = effective porosity (%)

h_t = water table height midway between drains after a certain time "t".

2.3.1. Drainage intensity factor "a"

The drainage intensity factor "a" was calculated by using the following equations as recommended by Dieleman (1972):

$$a = \frac{2.3\ (\log h_o - \log h_t)}{t} \qquad (2)$$

$$a = \frac{2.3\ (\log q_o - \log q_t)}{t} \qquad (3)$$

where:

h_o= initial water table height midway between drains, m.

h_t= water table height midway between drains after a certain time t.

q_o, q_t= drainage rate at beginning (t=o) and (t=t) of the selected observation period.

The h_t, q_t and h_o, q_o values are points of the straight part of the lines and were selected freely, by taking into account that h_o, q_o presents an earlier data than h_t, q_t.

2.3.2. Days after cessation of the recharge "t_A"

Days after cessation of the recharge was calculated from the Dieleman formula (1972) as follows:

$$T_A = \frac{0.4}{a} \qquad (4)$$

where:

0.4 = constant

a = drainage intensity factor "a" (days^{-1})

2.3.3. Thickness of phreatic aquifer:

The thickness of phreatic aquifer was calculated by using the equation

$$D = D_o + \frac{h_o + h_t}{4} \qquad (5)$$

as recommended by Glover and Dumm (1954)

Where: D_o = depth of impermeable layer (m)

h_o, h_t= as previously noted.

The depth of impermeable layer "D_o" was calculated after differentiating the steady state of Hooghoudt (1940):

$$d = \frac{D_o}{\frac{8\,D_o}{\pi L} \ln \frac{D_o}{U} + 1} \qquad (6)$$

Then, we obtain

$$D_o = \frac{\pi L}{8} \qquad (7)$$

Where d is equivalent depth (m), L is drain spacing (m), $U = \pi r$ is wetted perimeter of drain (m), and r is the radius of drain pipe = 0.10 m

The thickness of equivalent depth "d" was calculated by the following equation (El-Hamchary 1980):

$$d = \frac{h_o\, h_t\, \left(e^{0.7877 \ln 1.16 \frac{h_o}{h_t}} - 1 \right)}{2\,\left(h_o - h_t\, e\; 0.7877 \ln 1.16 \frac{h_o}{h_t}\right)} \qquad (8)$$

Where h_o and h_t are the heights of water table midway between drains at times

t = t and t = t + st, respectively

2.3.4. Hydraulic conductivity "K" and transmissivity "KD"

The hydraulic conductivity "K" was calculated by the following two equations according to Dieleman (1972).

$$Kd = \frac{q}{h} \cdot \frac{L^2}{2\pi} \qquad (9)$$

and

$$Kd = \frac{afL^2}{\pi^2} \qquad (10)$$

where a,d,q,h,f,L values were obtained as previously mentioned. Then, the "KD" value was calculated from the obtained K and D values.

2.3.5. Effective porosity "f"

The effective porosity "f" was calculated from Glover and Dumin equation (1964) as follows:

$$f = \frac{q}{h} \cdot \frac{\pi}{2a} \qquad (1)$$

In addition, it was calculated from the volume (w) of water released by the soil when the water table drops from position h_o to position h_t in a known interval during the tail recession, according to the expression recommended by Dieleman (1972).

$$W = 0.7\ f\ (h_o - h_t) \qquad (11)$$

Where "W" is calculated from the measured discharge rates.

2.3.6. Flow resistance

The total resistance can be expressed by the following equation (Ernst 1962)

$$W_{t_o}t = h \div ql \qquad (12)$$

Where:

h = is available hydraulic head (m.)
L = is drain spacing (m.)
ql = is rate of ground water flow two sides into a unit length of drain (m^2/day).

The horizontal resistance "Wh" and radial resistance "Wr" was also calculated according to the formula of Ernst (1962).

$$"W_h" = \frac{L}{8\ KD_o} \qquad (13)$$

$$"W_r" = \frac{1}{\pi K} \ln \frac{D_o}{\pi r} \qquad (14)$$

Where:

KD_o is transmissivity m^2/day
L is drain spacing (m.)
D_o is thickness of phreatic aquifer (m.)
r is radius of drain pipe (0.10 m.)

After obtaining "$W_{t_o}t$", and "W_r", then the entrance resistance "W_e" was calculated from the expression:

$$"W_e" = "W_{tot}" - ("W_h" + "W_r") \qquad (15)$$

2.3.7. Hydraulic head losses:

The total head loss of hydraulic head for flow (available hydraulic head, from t_o to t) into a pipe drain was calculated as:

$$"h"_{total} = "h_h" + "h_r" + "h_e" \qquad (16)$$

Where: h_h, h_r and h_e refer to the horizontal, radial and entrance head loss respectively.

The ground water flow to the drain was expressed in the general form equation (10) as

$$h = W \cdot ql \qquad (17)$$

Where: h is the type of head loss (i.e. h_{total}, h_h, h_r and h_e), W . ql is rate of ground water flow two sides into a unit length of drain (m^2/day).

2.3.8. Recharge to ground water and storage capacity:

According to Kraijenhoff Van de Leur (1958) and Wessling (1974), recharge to ground water "R" was calculated by the following equation:

$$\text{Recharge to ground water "R"} = \frac{h_t \pi a f}{4\ (e^{atr} - 1)(e^{-at})} \qquad (18)$$

Where:

h_t = avaialable hydraulic head at time t days after beginning to the recharge (m.)

t = time after beginning of recharge (days)

$t_A = \frac{0.4}{a}$ days after cessation of recharge

t_r = period of steady recharge, corresponding to time of irrigation application (days)

f = drainable pore space (or effective porosity)%

d = drainage intensity factor (days $^{-1}$)

The storage capacity "S" was calculated according to Ward (1967) as difference between recharge to groundwater and drain discharge Storage capacity "S" = recharge to ground water "R" - Drain discharge "q" (19)

2.3.9. Drain spacing required

The modified Glover - Dumm equation (Dumm 1960) was used to calculate the required drain spacing.

$$L = \pi \left(\frac{kdt}{f}\right)^{\frac{1}{2}} \left(\ln 1.16 \frac{h_o}{h_t}\right)^{-\frac{1}{2}} \qquad (20)$$

Where: L, k, d, t, f, h_o and h_t as previously mentioned.

3. Results and Interpretation

3.1. Ground water flow condition

The condition under which the ground water flows towards the drains were determined by daily measurements of the water table and discharge. Hydrographs of drain discharge and hydraulic head were drawn for several seperate periods starting from the first day after irrigation and the successive days for the drained fields under investigation. It is clearly obvious from figures 2, 3, 4, 5, 6, 7, 8, 9 and 10 that the drop of water table levels corresponds with drain discharges which differ from day to day. The obtained results could be explained on the basis that lowering the water table by means of drainage has given the top soil a chance to dry and permit shrinkage and formation of water passageways which permit a much easier pathway for movement of water into drain pipes. It is worthwhile to note that the drying process and its consequences through drainage plays an important role in improving the soil structure of clay soils.

To give a clear picture, the relation between the hydraulic head and discharge rate could be obtained as shown in figures 11, 12, 13, 14, 15 and 16. At a certain time "t_A" after cessation of recharge, this relation becomes approximately constant. Figures 17, 18, 19, 20, 21, 22, 23 and 24 show the hydraulic head and discharge rate on semi - logarithmic paper. The obtained lines during tail recession are parallel. This means that part of the drainage water in these soils is passing through the layers below drains, i.e. where the equations on non-steady state are applicable. It also means that the conditions for which the modified Glover-Dumm equation were drived are fulfilled. In that respect, May and Trafford (1977) reported that flow in the clay soils is predominately in the surface layers and hence via the trench zone to the pipe when relatively widely spaced drains are used.

3.2. Drainage intensity facrtor "a"

For the sake of evaluating the drainage system after 5 years from date of installation, a drainage intensity factor was

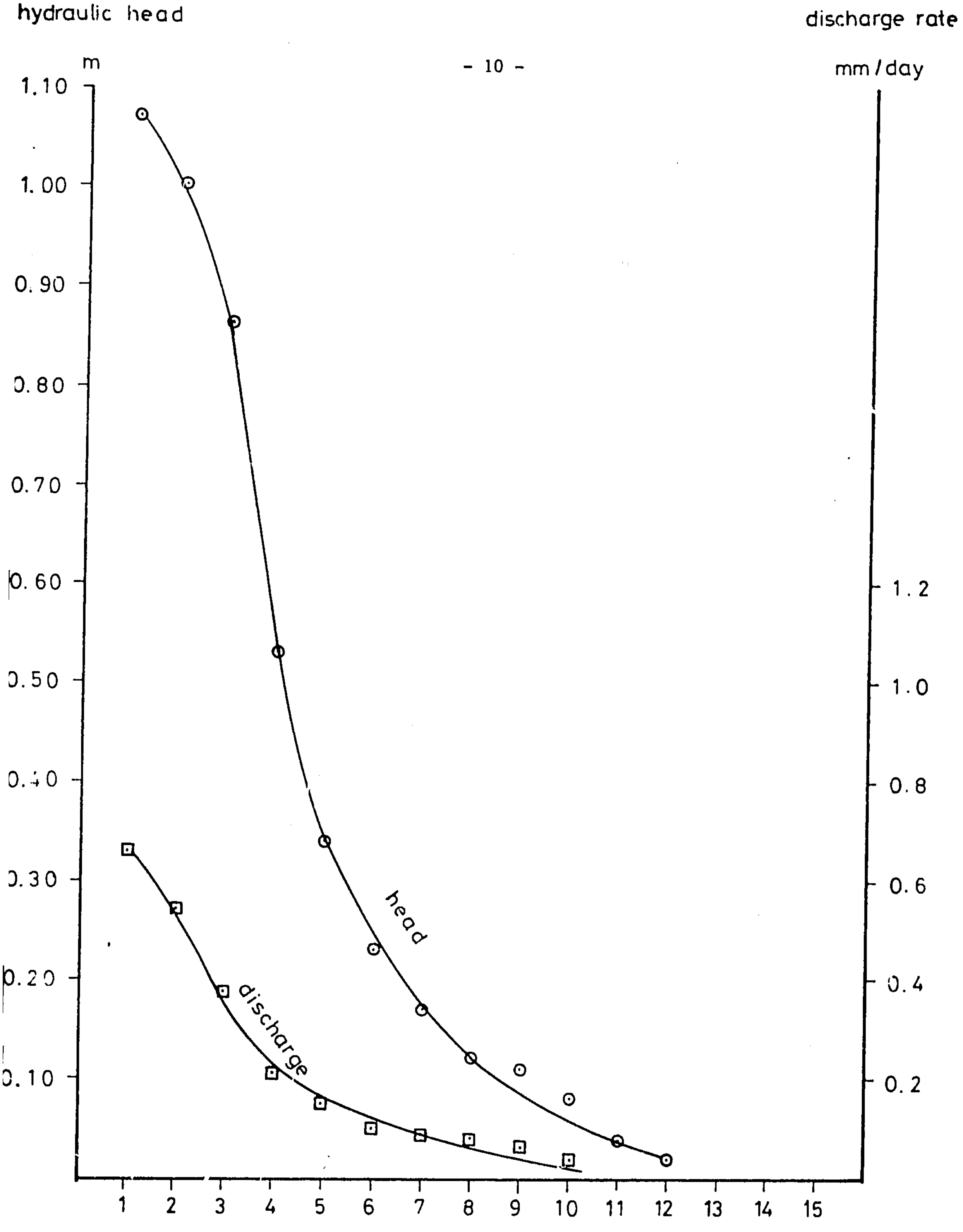

Fig.(2) : Water table position and discharge rates observed and converted into hydraulic head (m) & discharge rates (mm/day) for subsurface lateral No. (1).

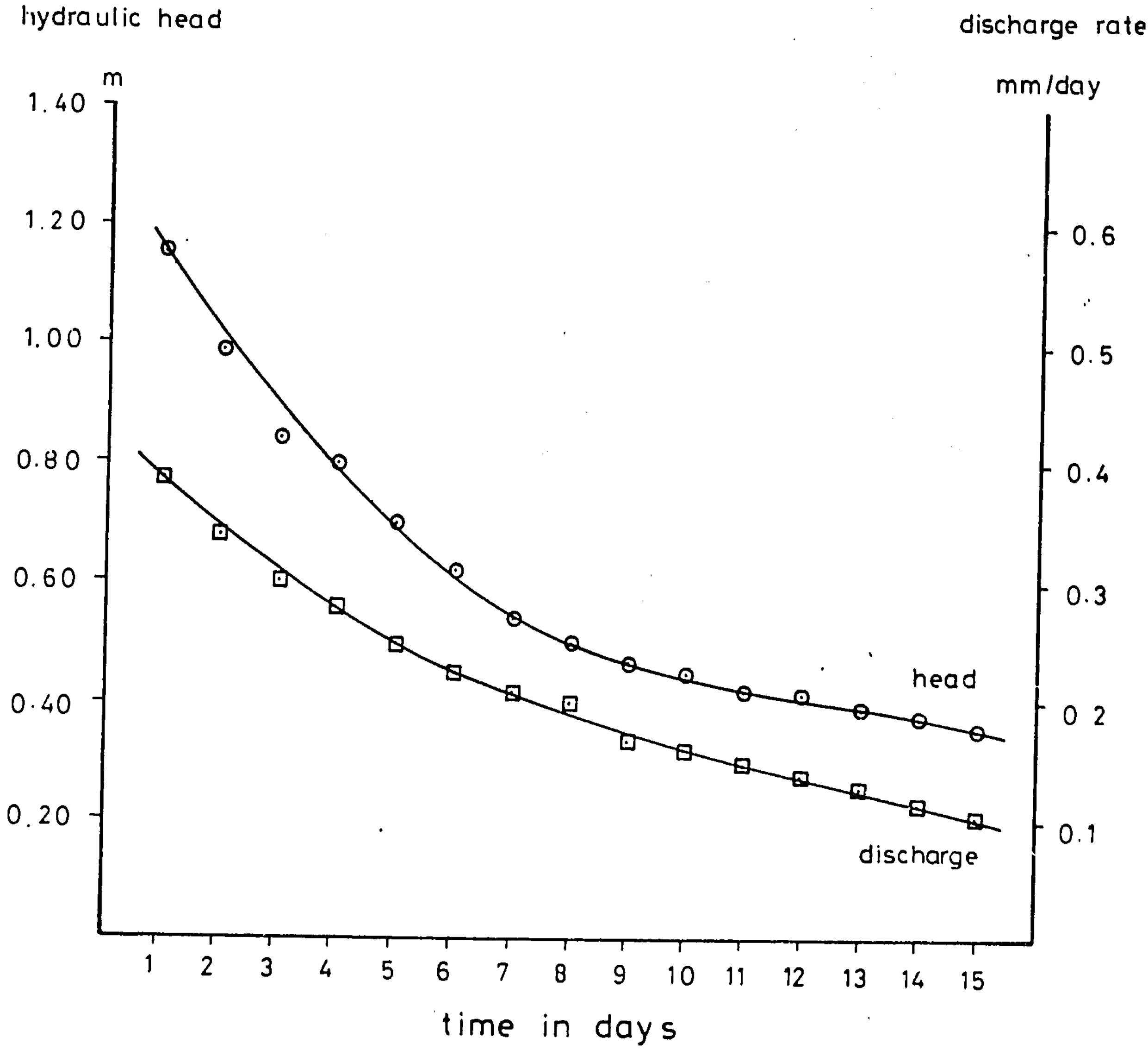

Fig.(3) : Water table position and discharge rates observed and converted into hydraulic head (m) & discharge rates (mm/day) for subsurface lateral No.(2).

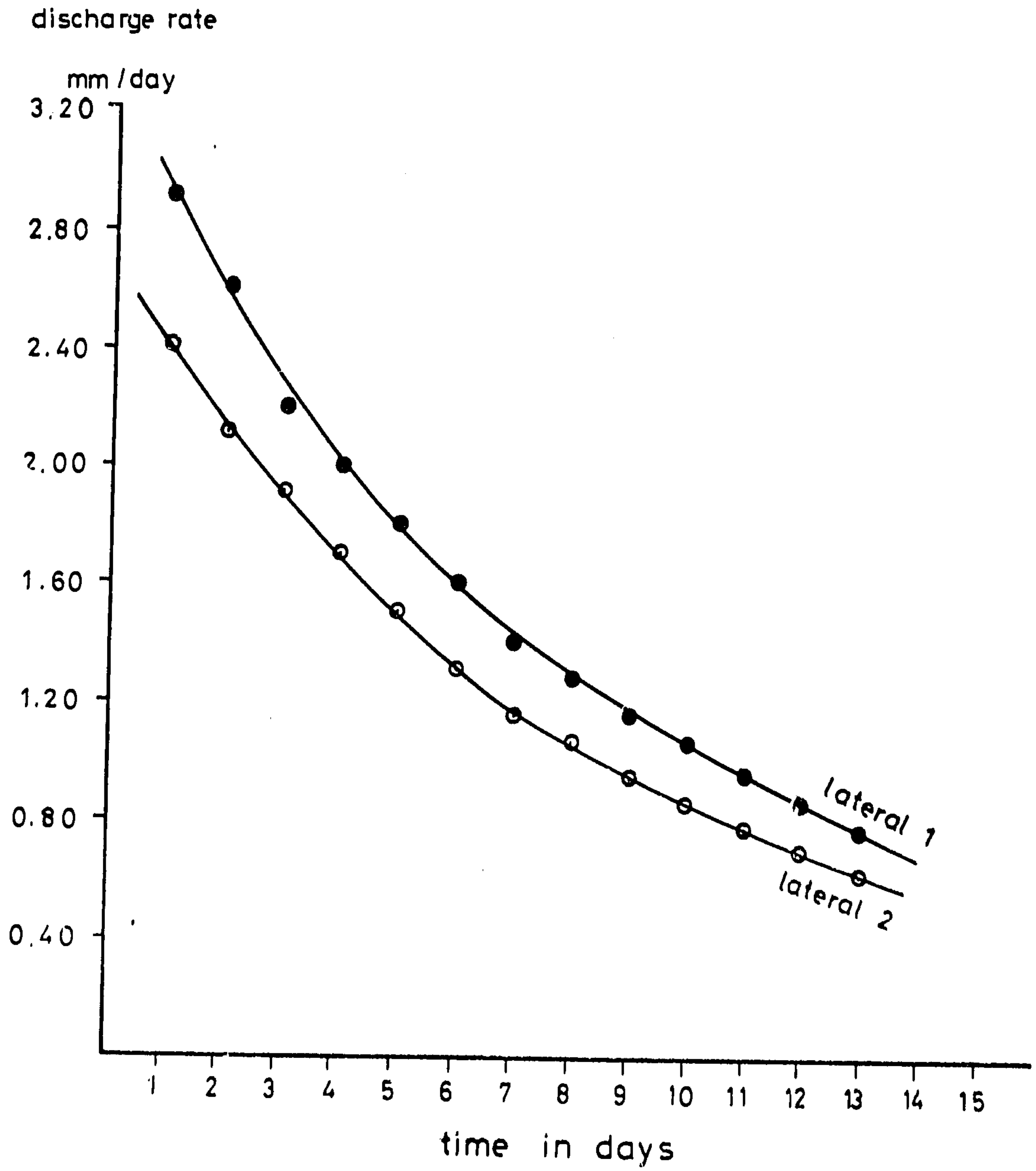

Fig. (4) : Discharge rates observed and converted into discharge rates (mm/day) for subsurface laterals No.(3) and (4).

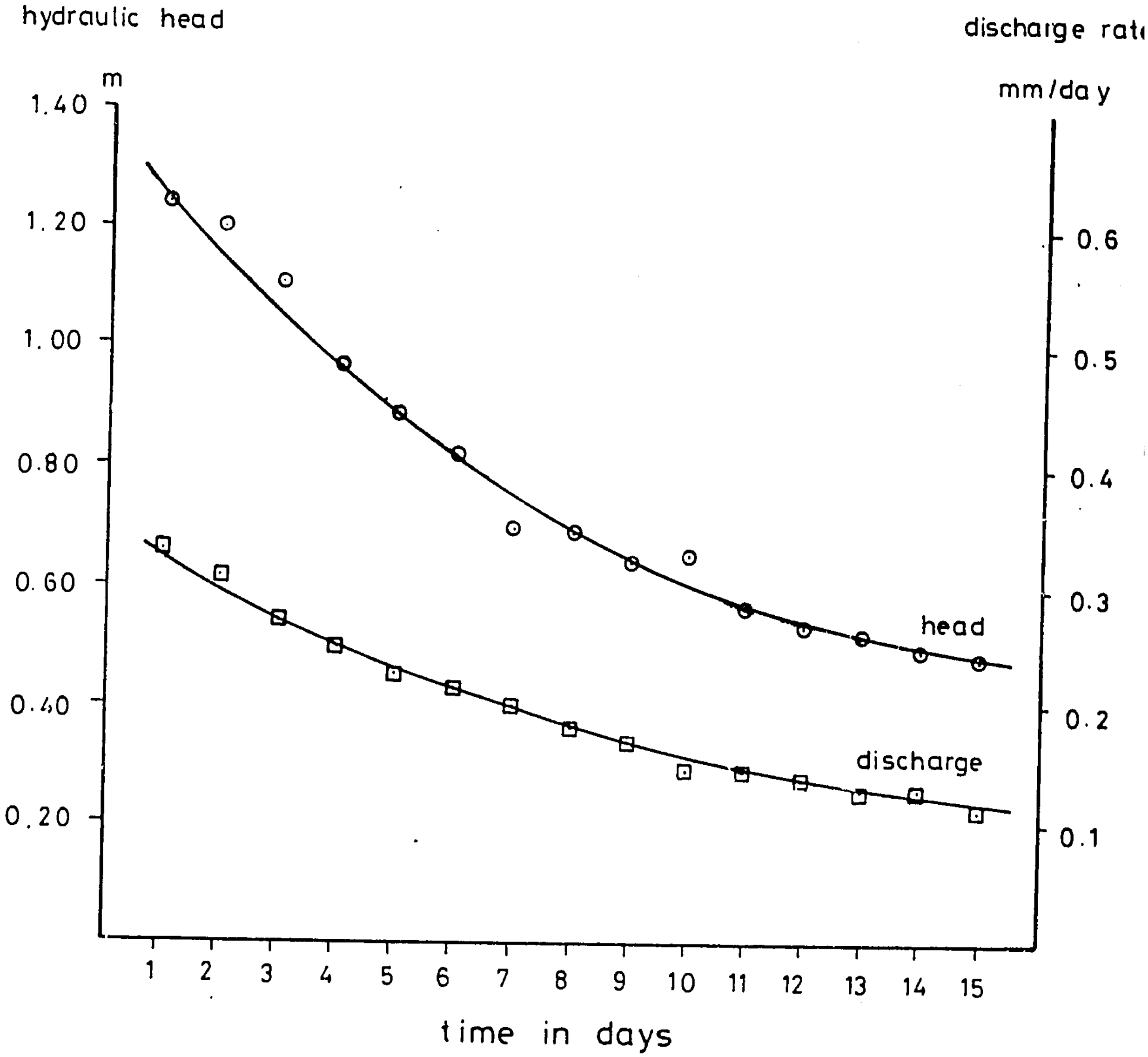

Fig.(5) : Water table position and discharge rates observed and converted into hydraulic head (m) & discharge rates (mm/day) for subsurface lateral No. (5).

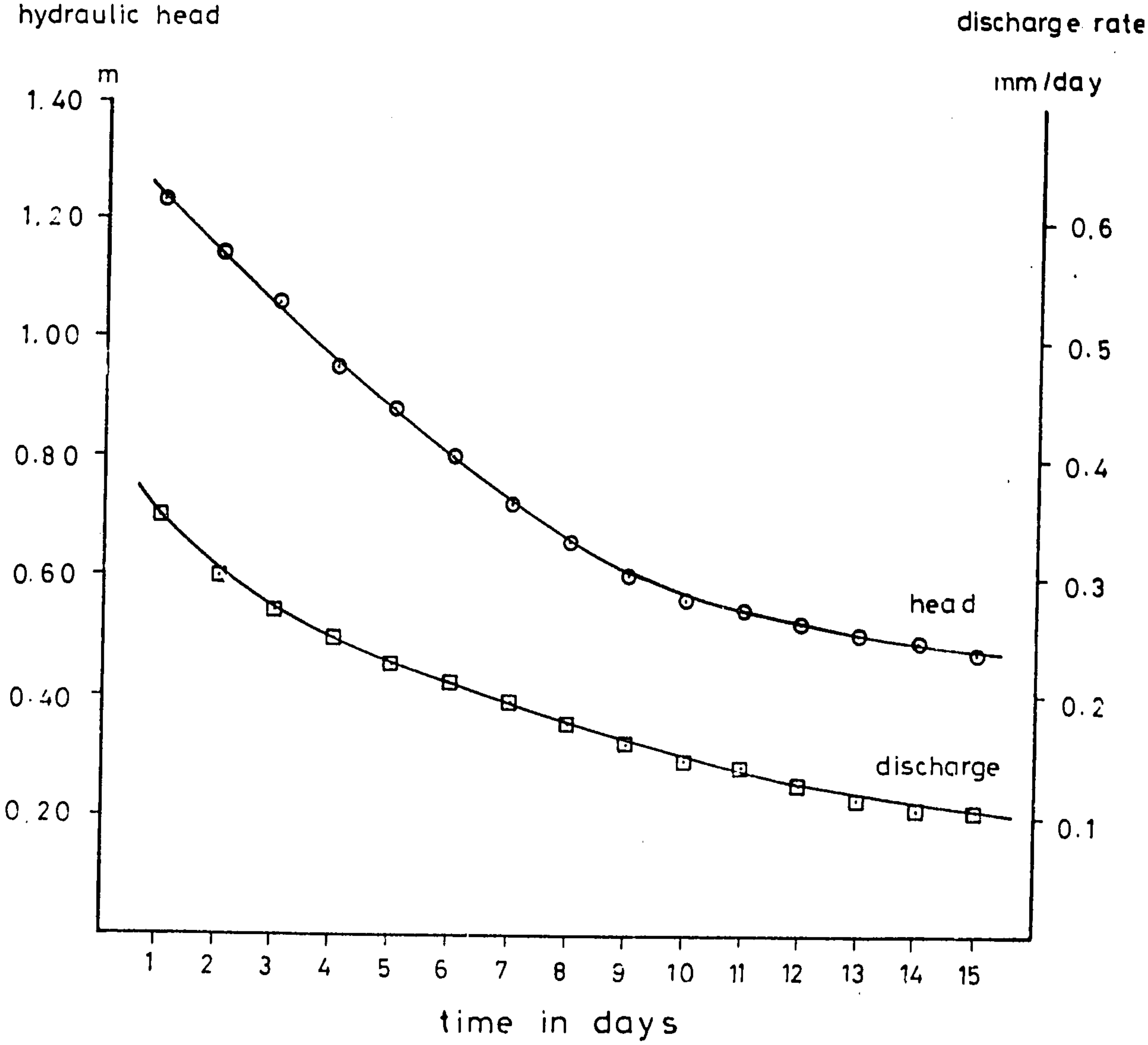

Fig.(6) : Water table position and discharge rates observed and converted into hydraulic head (m) & discharge rates (mm/day) for subsurface lateral No.(6).

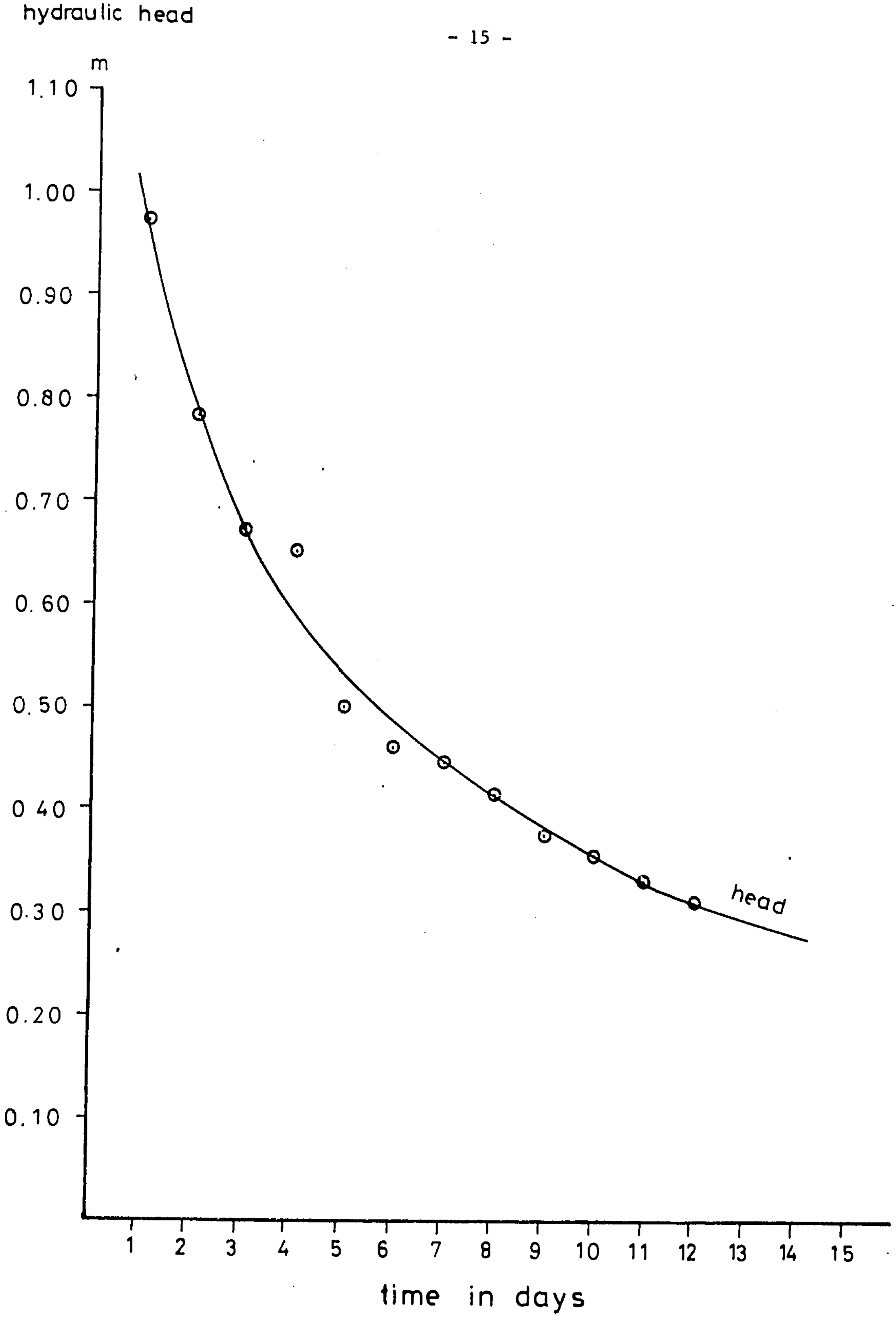

Fig.(7) : Water table position observed and converted into hydraulic head (m) for subsurface lateral No. (7).

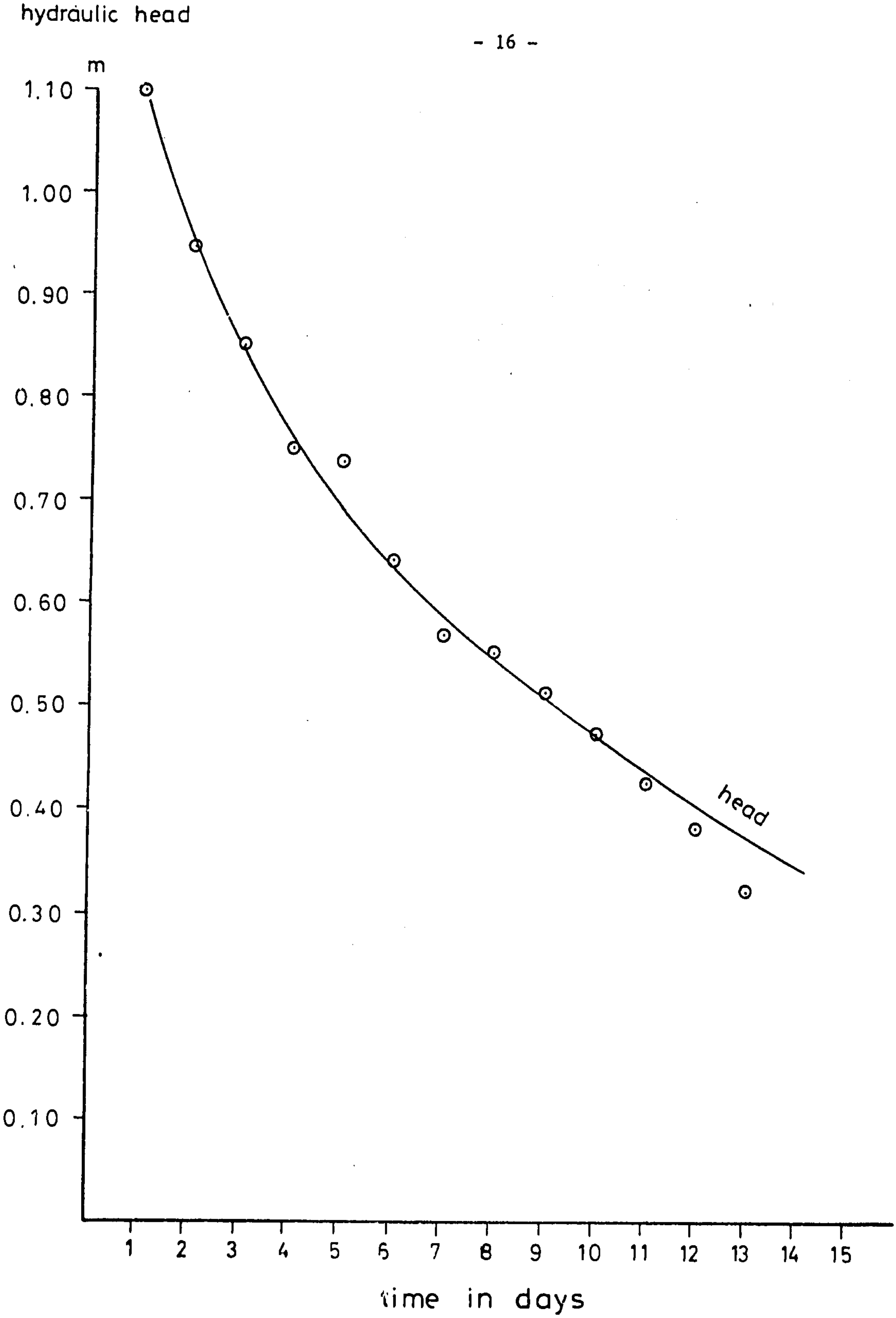

Fig.(8) : Water table position observed and converted into hydraulic head (m) for subsurface lateral No. (8) .

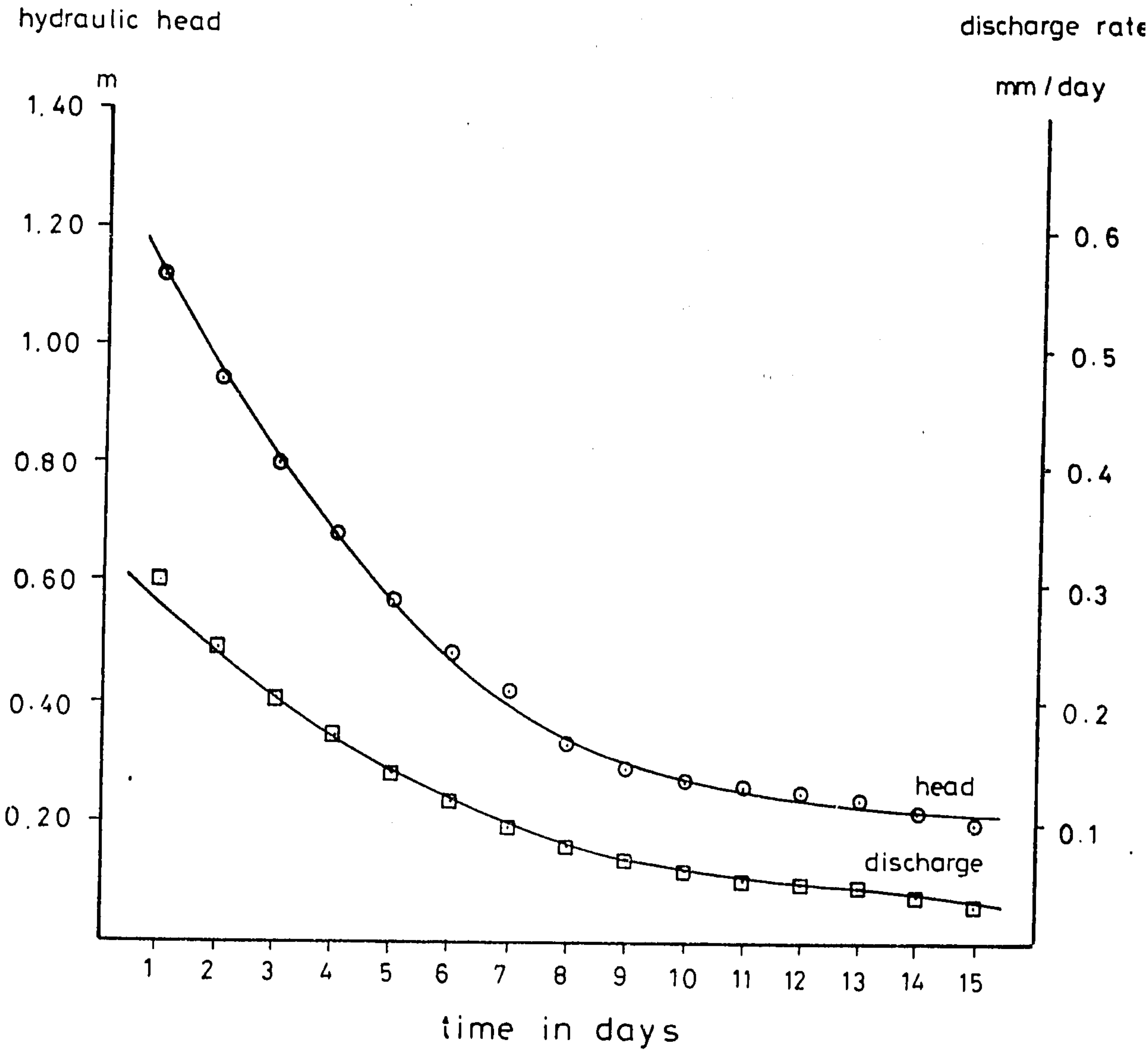

Fig.(9) : Water table position and discharge rates observed and converted into hydraulic head (m) & discharge rates (mm/day) for subsurface lateral No.(9).

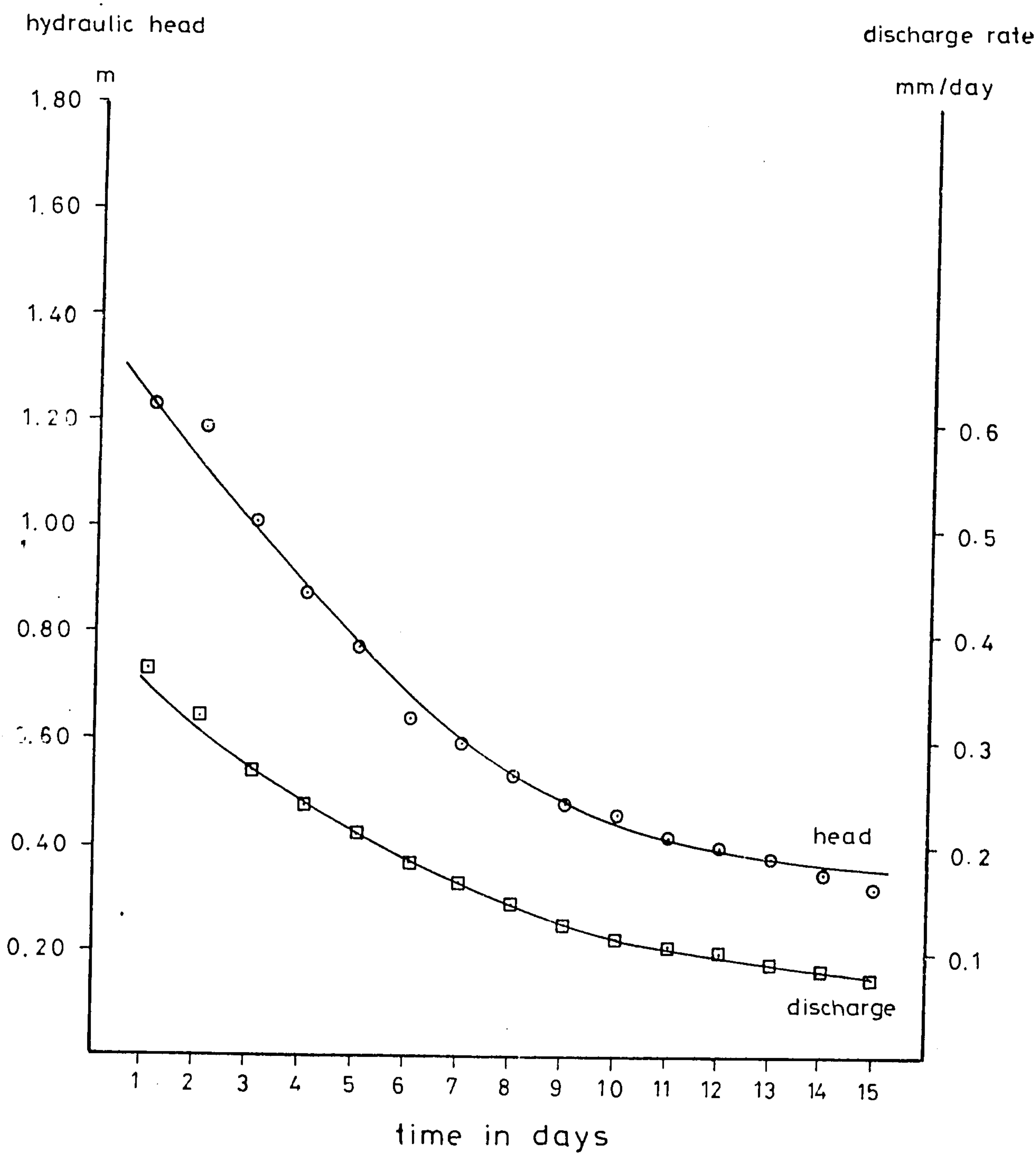

Fig.(10) : Water table position and discharge rates observed and converted into hydraulic head(m) & discharge rates (mm/day) for subsurface lateral No.(10).

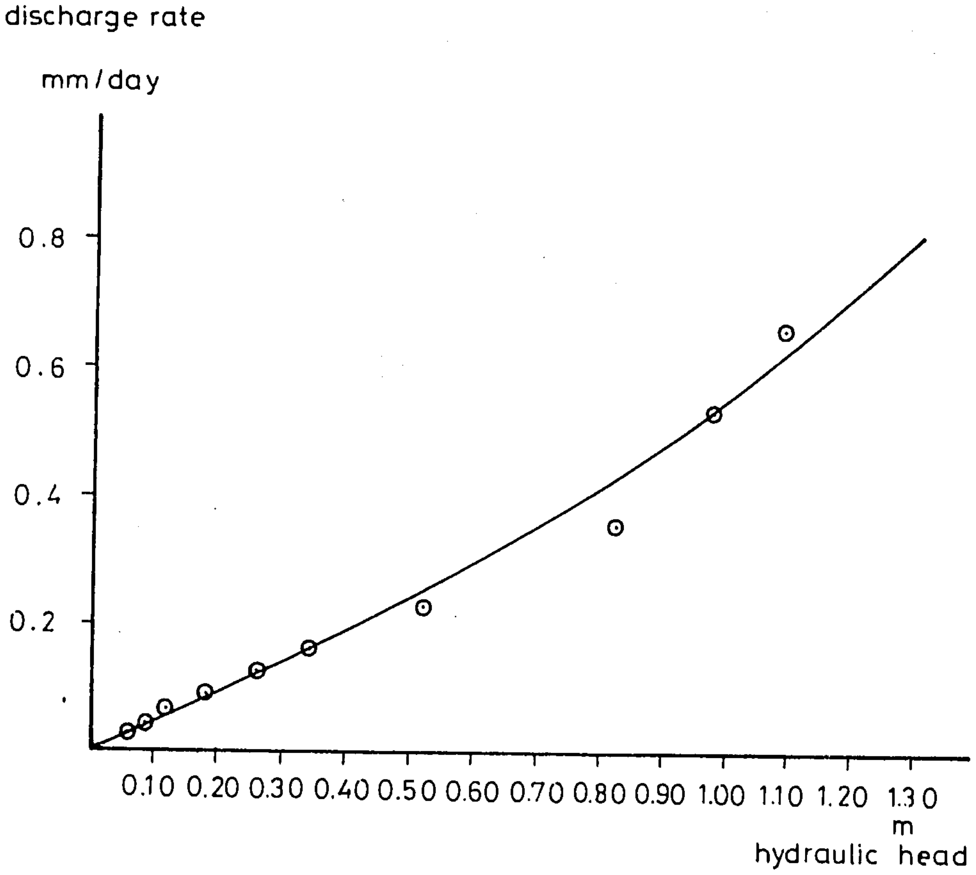

Fig.(11) : Discharge rate versus hydraulic head
Data taken from Fig.(2).

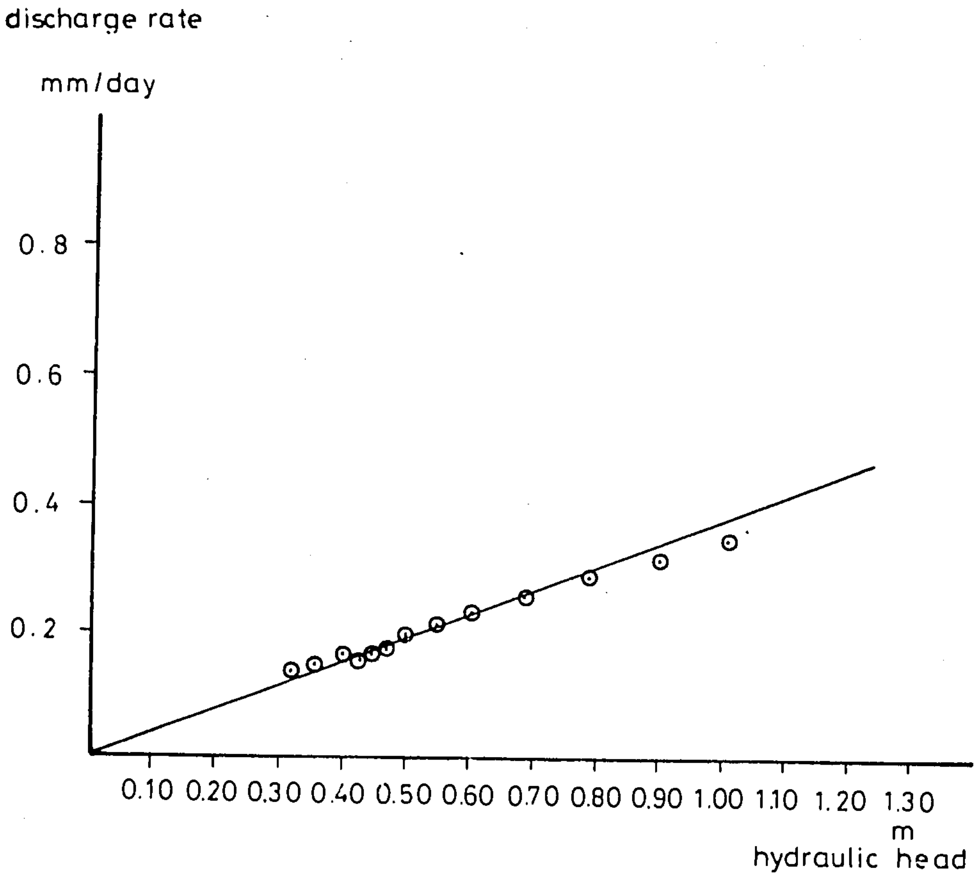

Fig.(12) : Discharge rate versus hydraulic head
Data taken from Fig. (3) .

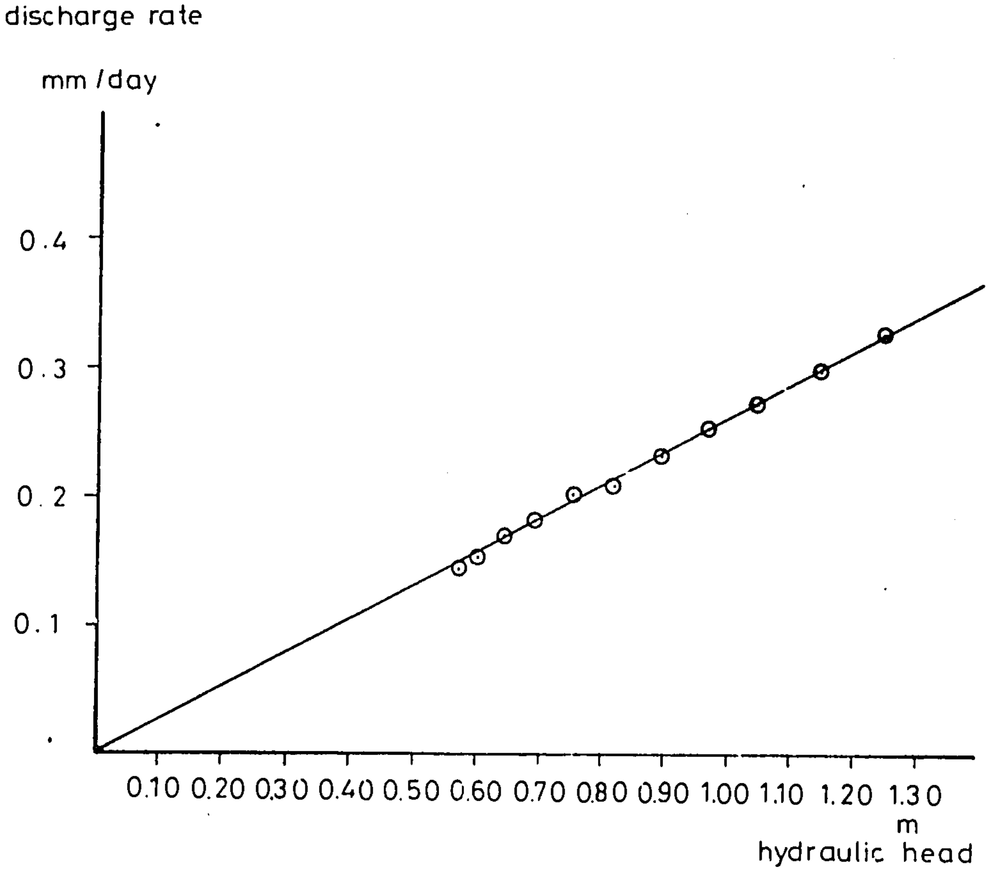

Fig.(13) : Discharge rate versus hydraulic head
Data taken from Fig. (5) .

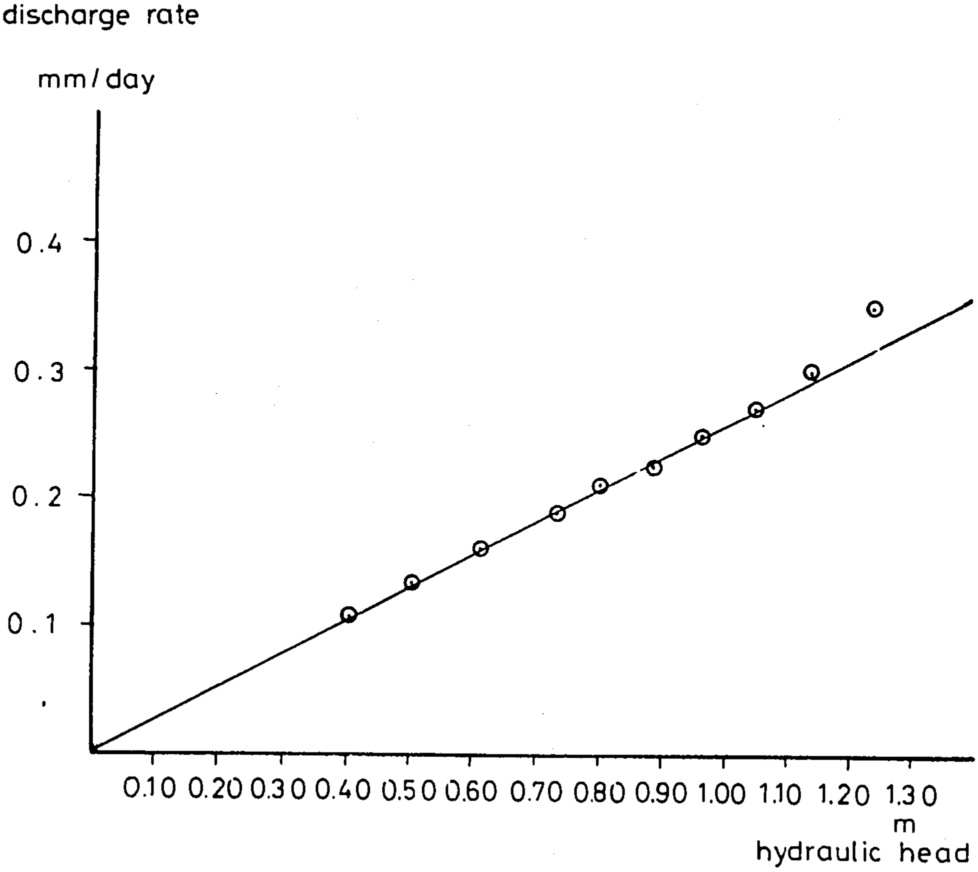

Fig. (14) : Discharge rate versus hydraulic head
Data taken from Fig. (6).

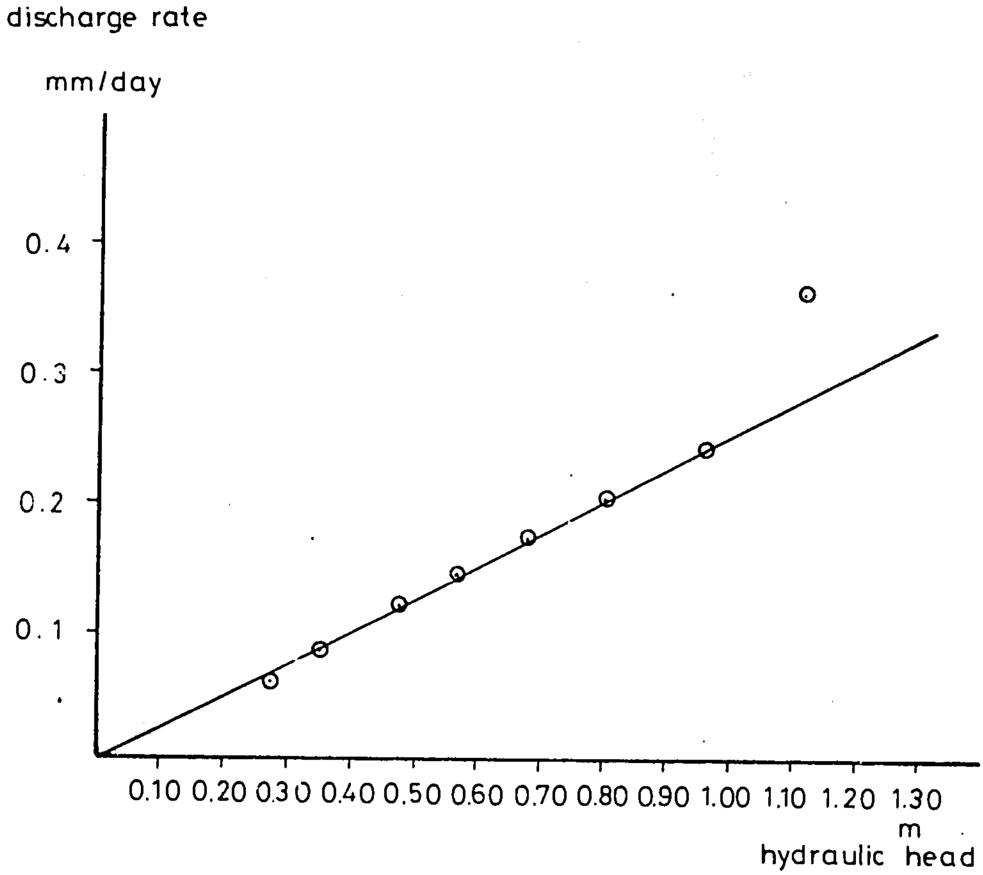

Fig.(15) : Discharge rate versus hydraulic head
Data taken from Fig.(9).

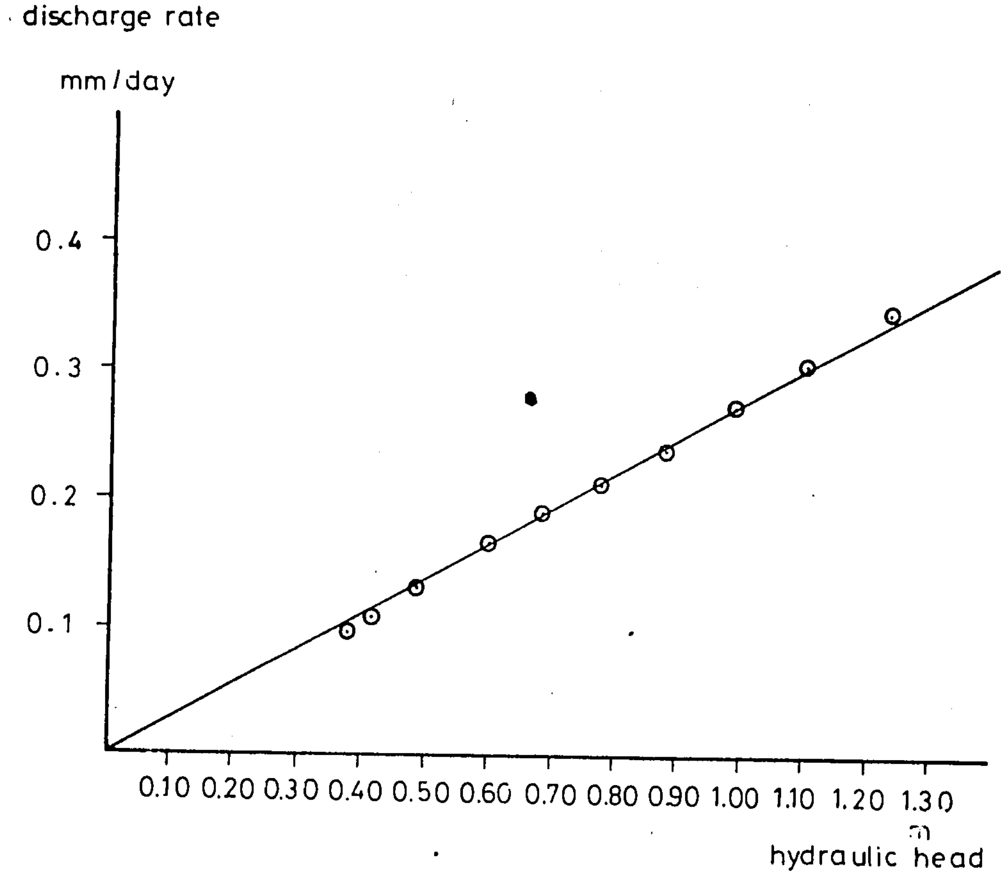

Fig.(16) : Discharge rate versus hydraulic head
Data taken from Fig.(10).

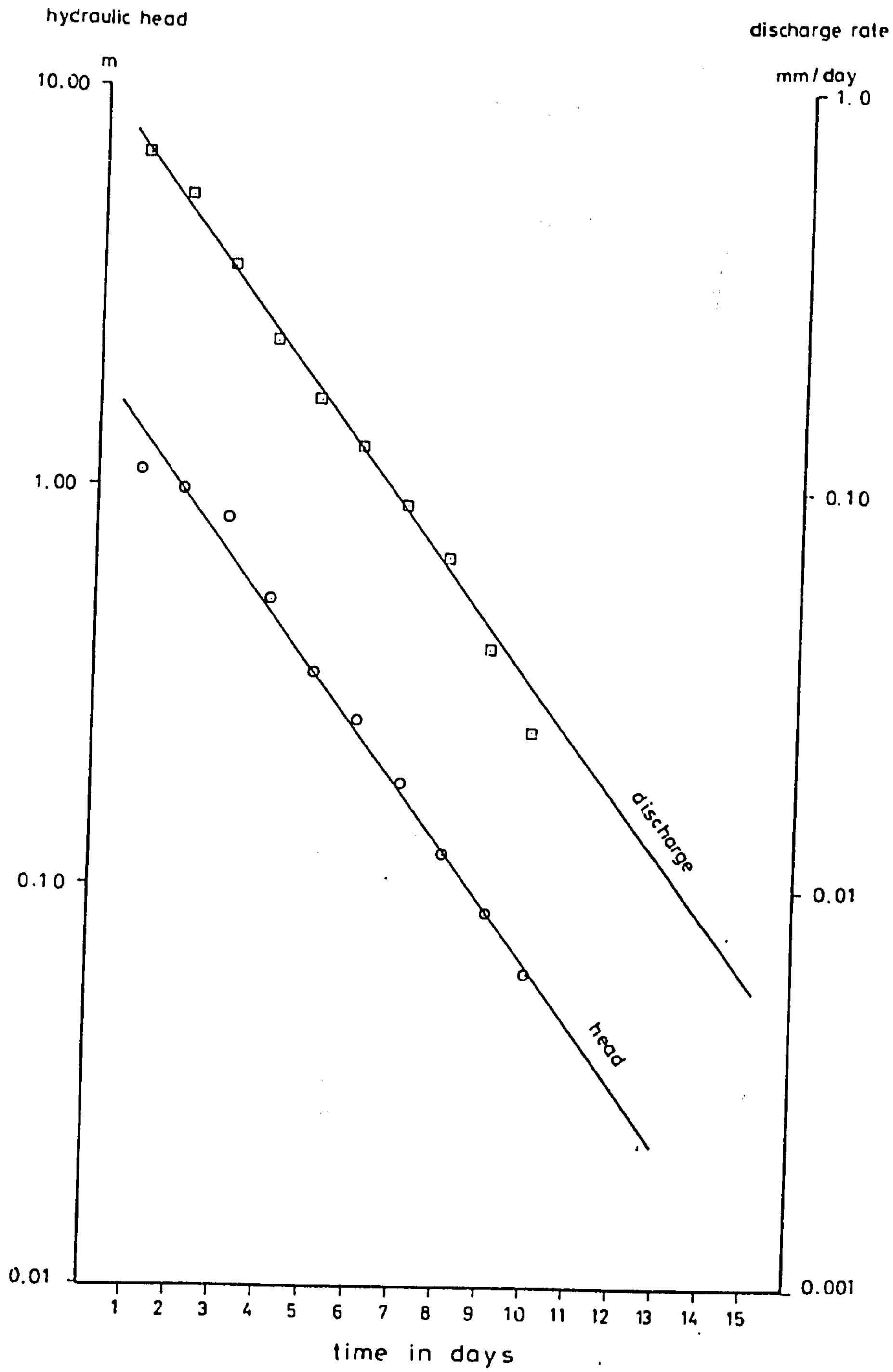

Fig.(17) : Plots of discharge and head versus time
Data taken from Fig. (2).

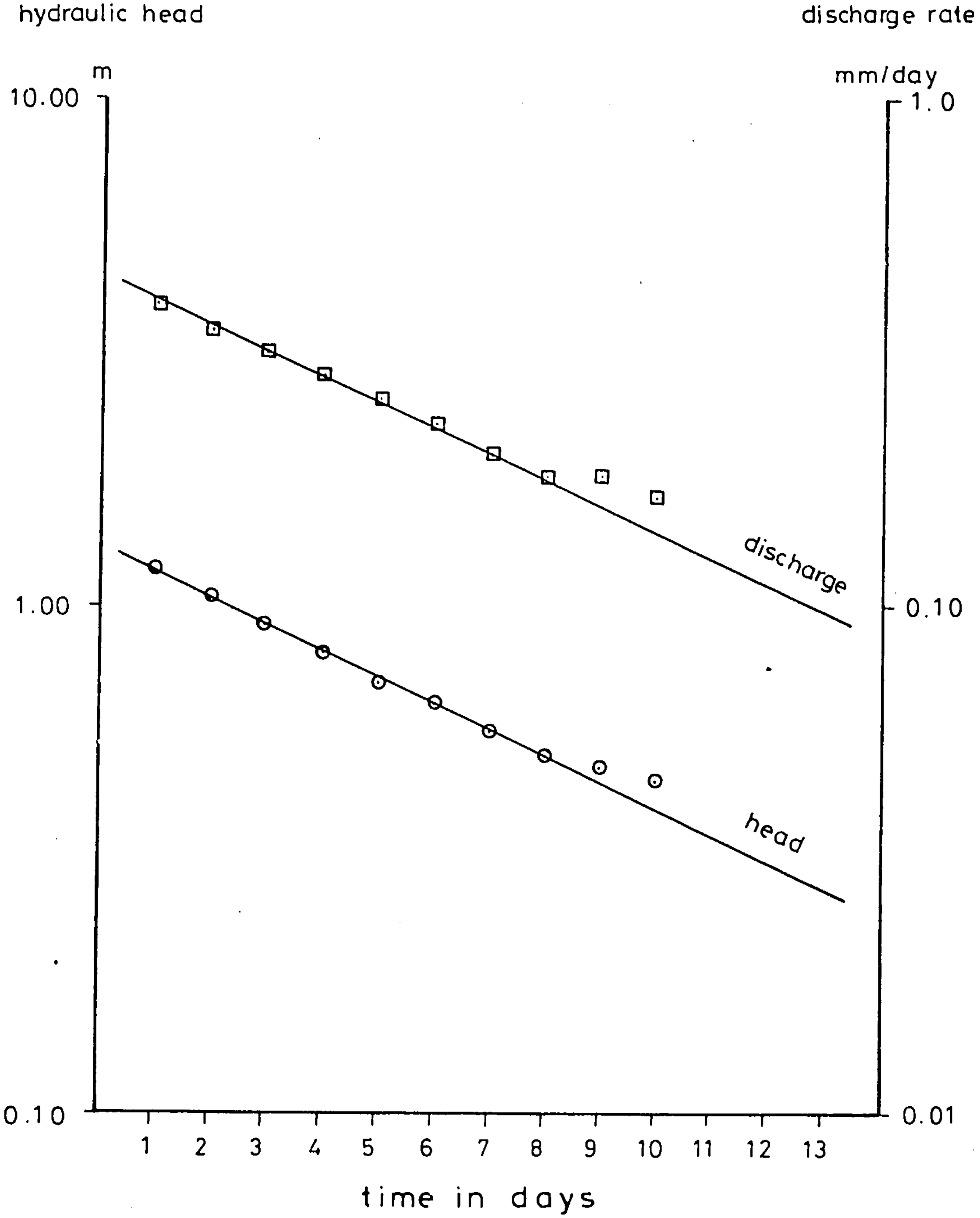

Fig. (18) : Plots of discharge and head versus time Data taken from Fig. (3).

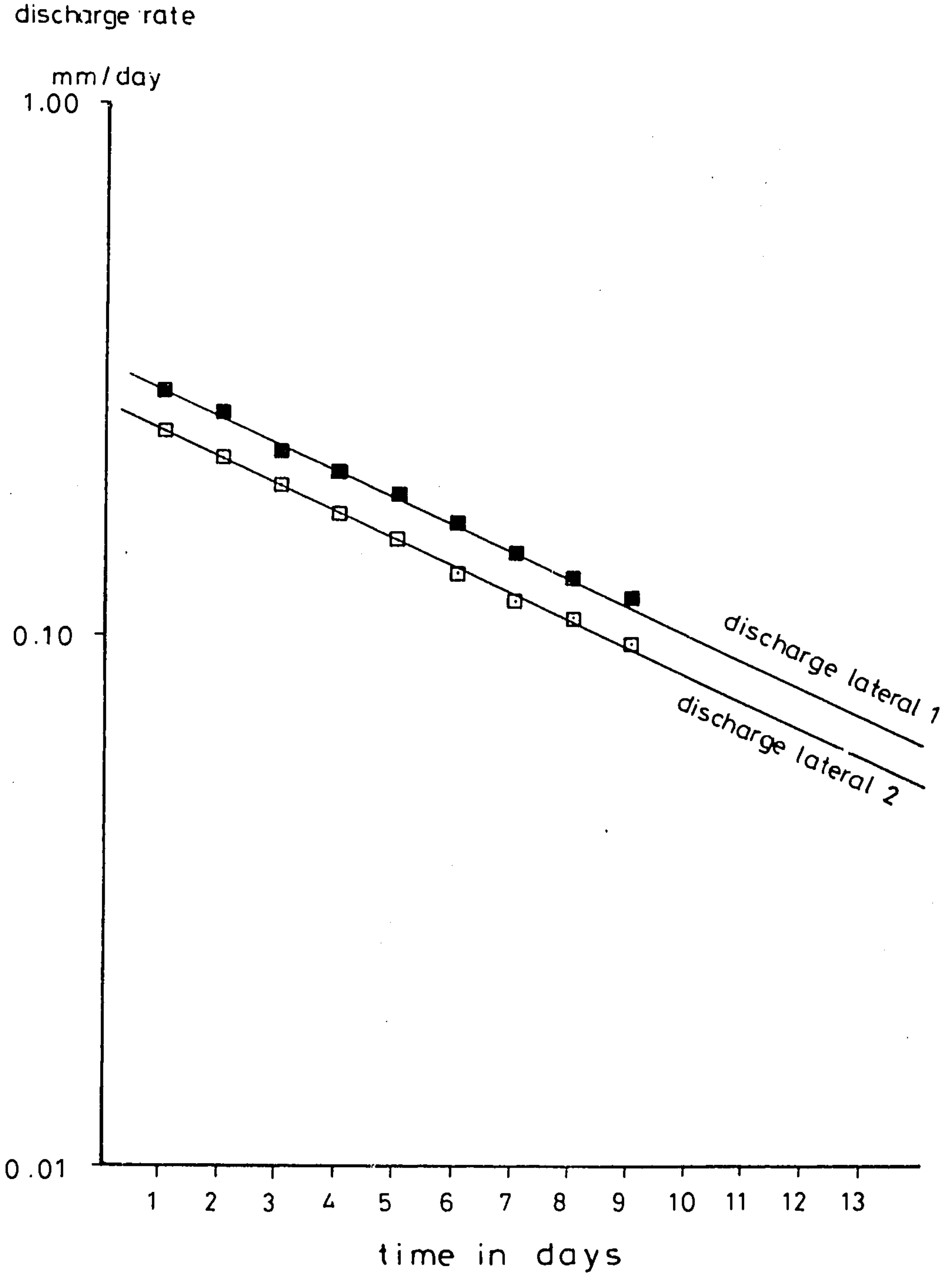

Fig.(19) : Plots of discharge and head versus time
Data taken from Fig. (4).

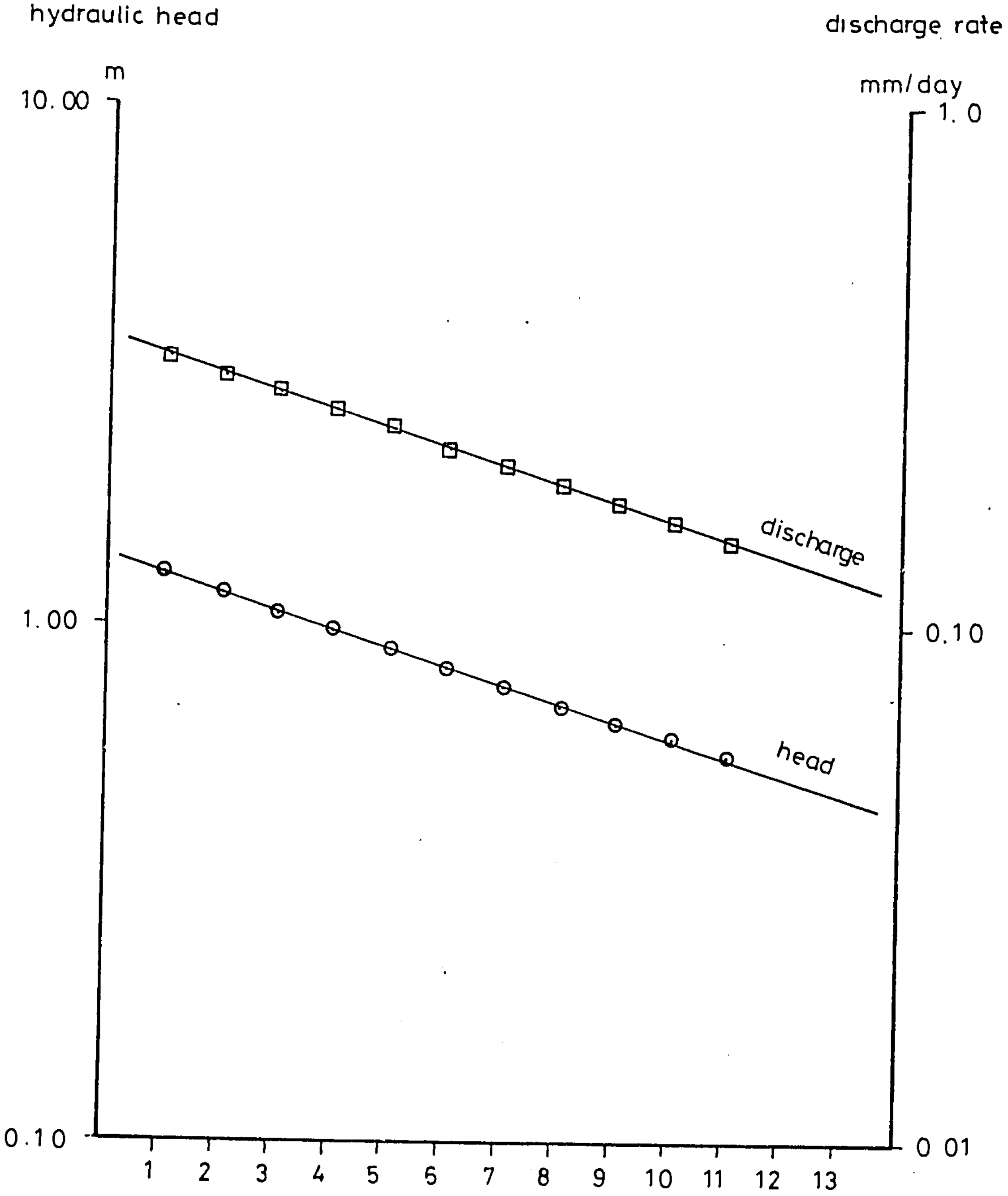

Fig. (20) : Plots of discharge and head versus time Data taken from Fig. (5).

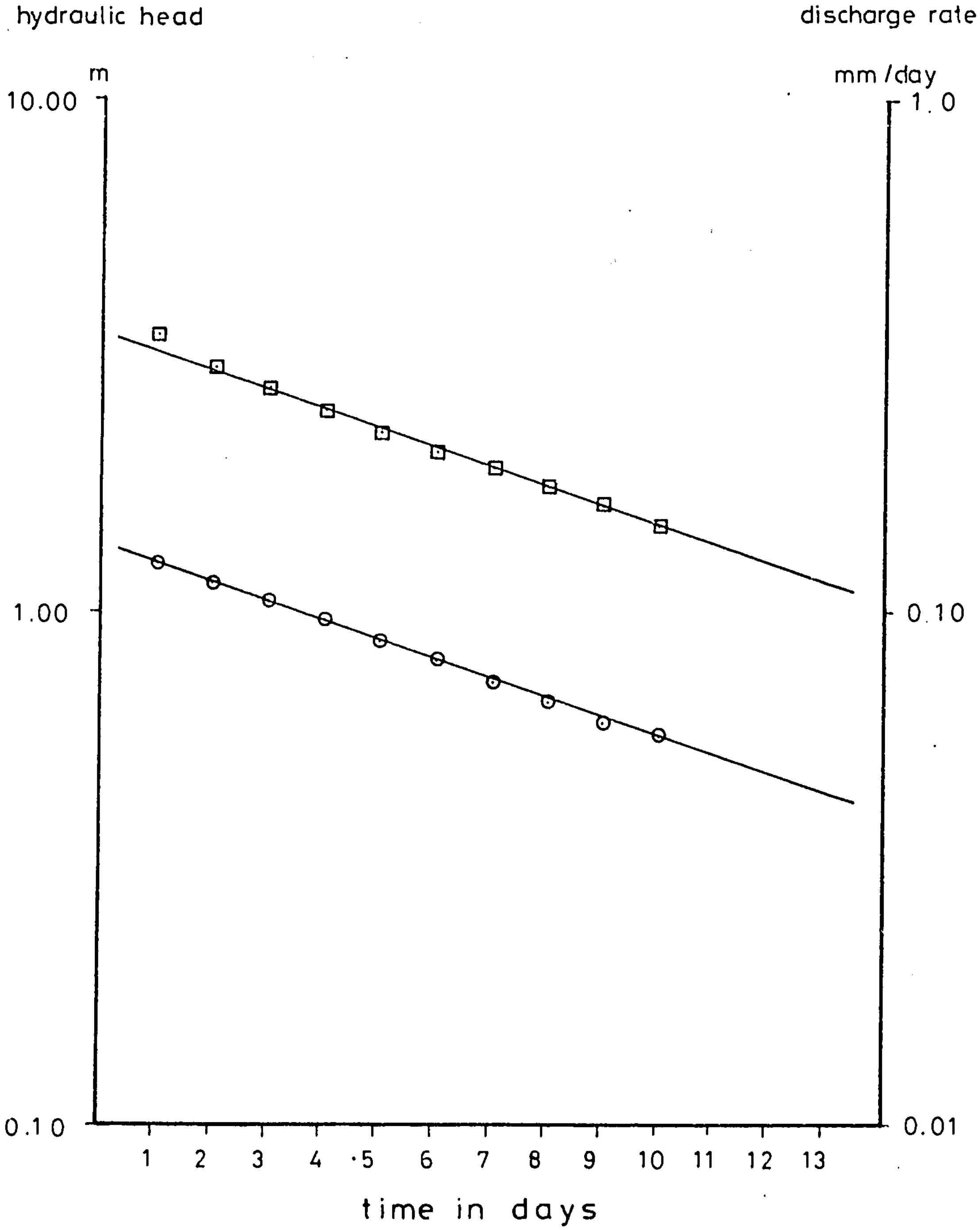

Fig.(21) : Plots of discharge and head versus time Data taken from Fig. (6).

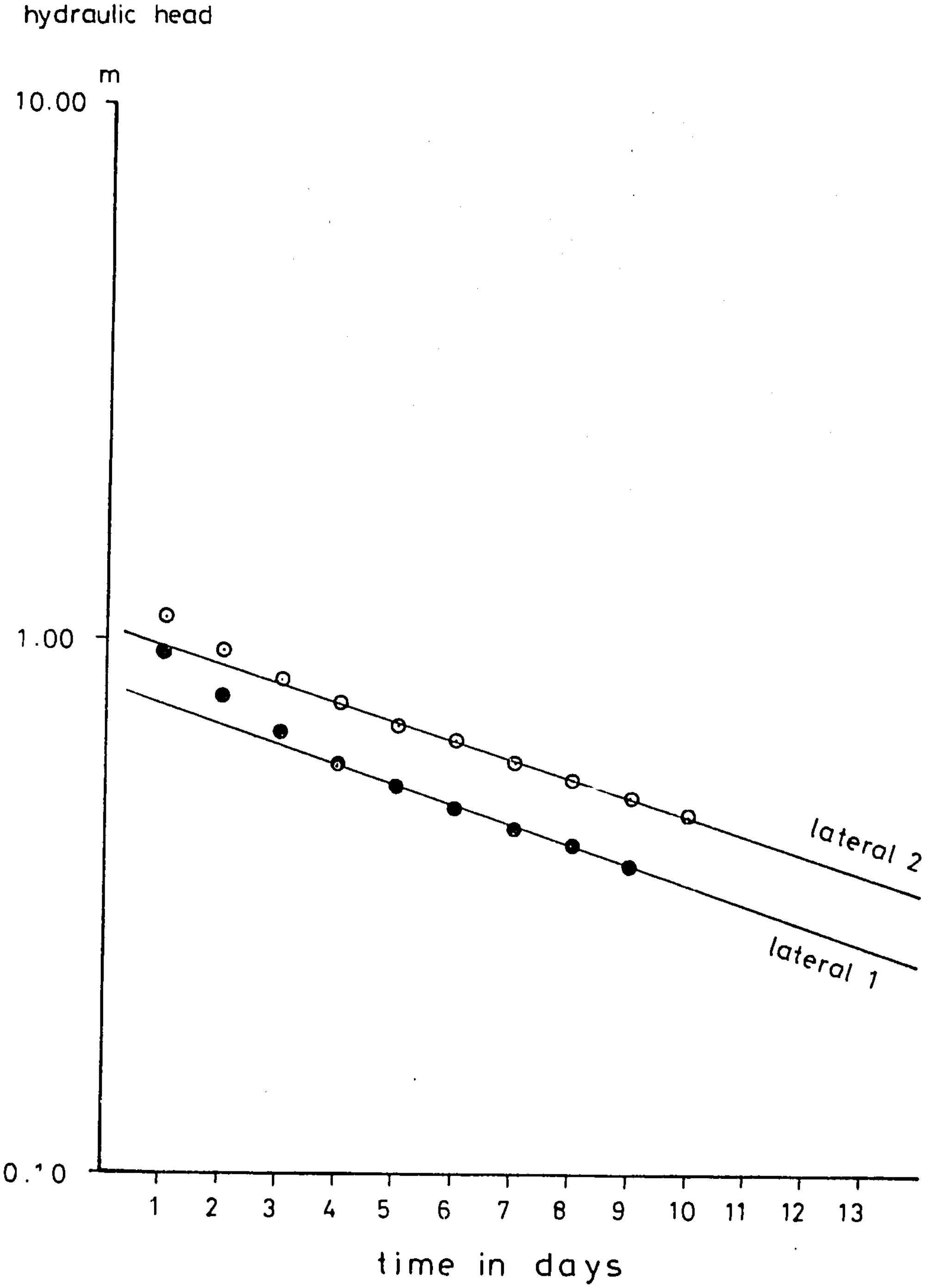

Fig.(22) : Plots of discharge and head versus time
Data taken from Figs.(7) and (8).

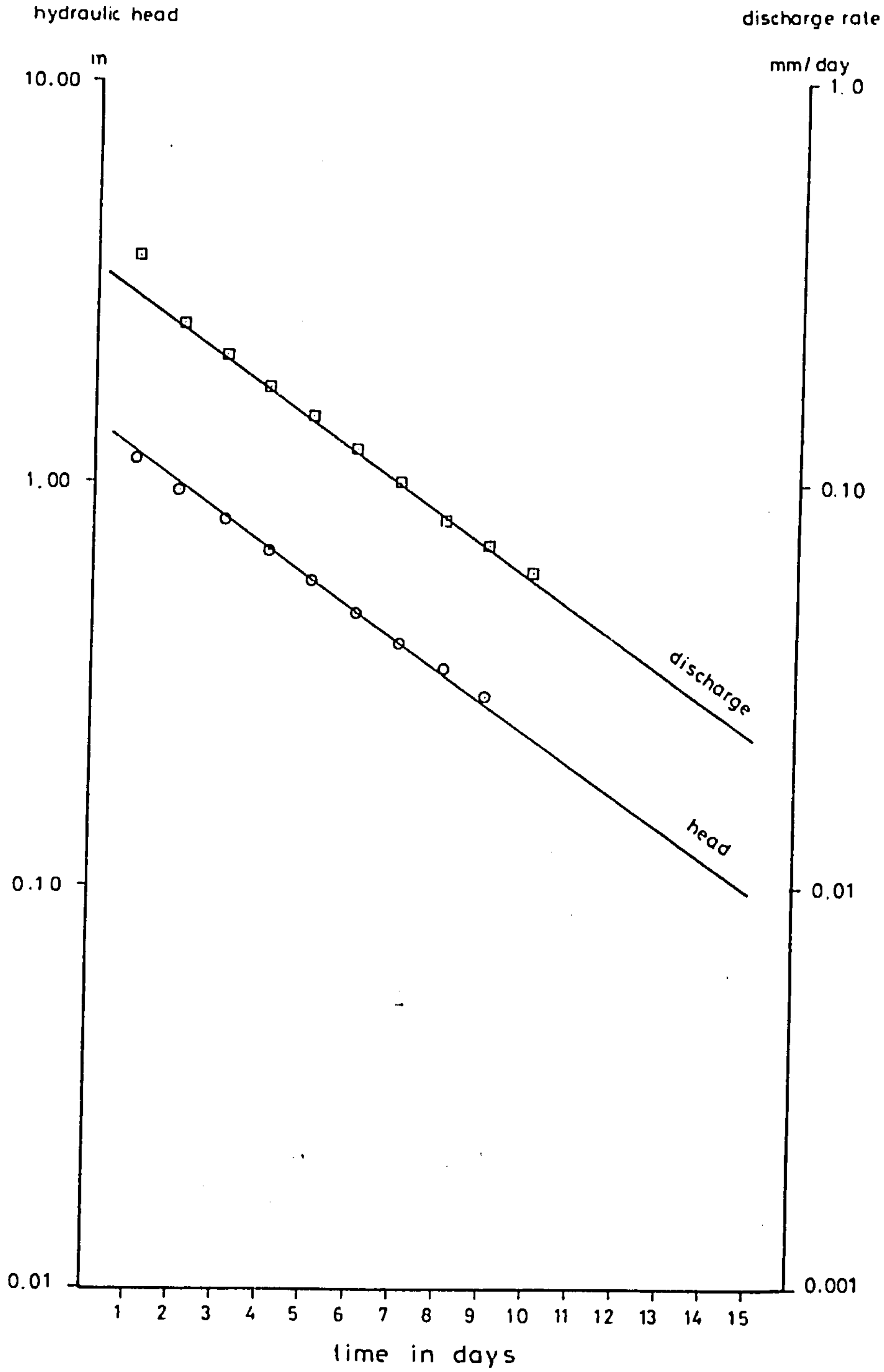

Fig.(23) : Plots of discharge and head versus time
Data taken from Fig.(9).

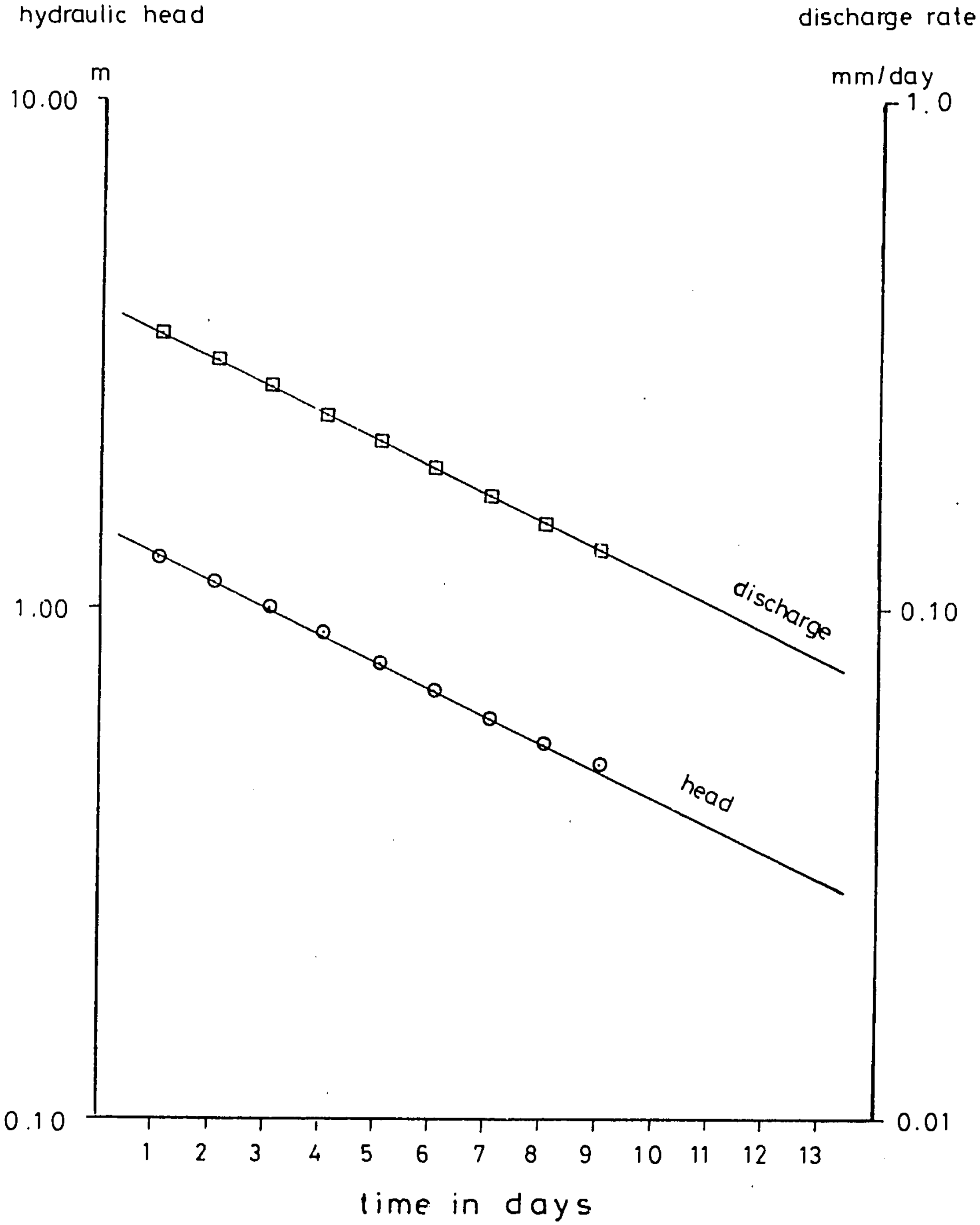

Fig. (24) : Plots of discharge and head versus time Data taken from Fig. (10).

calculated. The obtained data are given in Table 2. The results obtained reveal that the drainage intensity factor ranged from 0.081 to 0.342 days^{-1} and the average was found to be 0.134 days^{-1}. It is worth while to note that drainage intensity factor is low as a result of using widely spaced drain (40 m.) which caused a great loss, i.e. higher resistance of water flow near the drain. The obtained results confirm these suggestions regarding the direct or indirect effect of wide drain spacing on the drainage intensity factor. These findings, in fact, are similar to those obtained by Cavelaars (1974). May and Trafford (1977), Bailey (1979) and El Hamchary (1980). In that respect, Dieleman and Trafford (1976) reported the need for drainage testing to be conducted when there is significant radial flow resistance to the drains.

3.3. "Days after cessation of the recharge"

In order to give a clearer picture about the constant relation between discharge rate and hydraulic head after cessation of recharge, calculations were carried out to determine the point of time in a water table recession below which equations as shown in Table 2, are applicable in the processing of non-steady state flow data from the tested area. The results obtained reveal that the days after cessation of the recharge ranged from 2 to 5 days. While, the average was found to be 4.1 days. The obtained values are considered high due to the higher total resistance of the flow water path from land surface to the drainage system. These results are in accord with the findings of El-Hamchary (1980) who reported that days after cessation of the recharge was increased after 3 years from date of installation. He added that this may be due to the lower function of the trench backfill at 3 years from drain installation than in the earlier stages of removing excess irrigation water. In addition, the effects of wide drain spacing on the total resistance which are encountered, results in an increase in days after cessation of the recharge.

3.4. "Thickness of phreatic aquifer"

Thickness of phreatic aquifer indicates the thickness of soil transmitting water which may require draining. It depends on

Table 2. Drainage intensity factor and days after cessation of the recharge after processing the field drainage observations.

Drainage Parameter Lateral No.	Drainage intensity factor days^{-1}	Days after cessation of the recharge days
1	0.342	2
2	0.119	4
3	0.119	4
4	0.119	4
5	0.081	5
6	0.086	5
7	0.086	5
8	0.082	5
9	0.180	3
10	0.122	4

the depth to the impermeable layer and the downward movement of water during intensive periods of irrigation.

Therefore, claculations were carried out to obtain the depth of the impermeable layer "D_o". It was found to be 15.70 meters. Hooghaudt (1940) showed that when the depth of the impermeable layer below drain level exceeds ¼ of the drain spacing, the flow system can be treated as if such a layer was entirely absent. It has been observed by Kirkham (1940) that if the hard pan is deep enough the streamlines will not be affected in their upward movement to the tile.

With respect to the thickness of phreatic aquifer "D" shown in Table 3, calculations were carried out by using D_o = 15.70 m. for the drained fields under investigation. The obtained thickness of phreatic aquifer values ranged between 15.863 and 16.007 meters. These observations are in accord with the results obtained by Kirkham (1940) who showed that an impervious stratum at a shallow depth prevented many streamlines from reaching the tile. Also, those data obtained by Childs (1943) point out that the depth to the impervious layer, not only affects the streamline pattern, but also influences the height of the water table. Massland and Ha·kew (1958) confirmed these reusits as they showed that the impermeable layer affects the flow pattern, and the quantity of flow to drain lines is decreased.

The thickness of the equivalent layer "d" as calculated from the drainage field observations by El-Hamchary (1980) was found to be 2.80 m. and it is almost the same as the tabulated "d" obtained by Hooghoudt (1940) which was found to be 2.34 m. The obtained "d" value of 2.80 m. was used in the processing of all the data obtained from the drained fields under study.

3.5. Hydraulic conductivity

The hydraulic conductivity is obviously a sensitive indicator of the structural state of the soil. The hydraulic conductivity values from collected data on the field drainage and processing are presented in Table 3. According to the classification of O'Neal (1952), the hydraulic conductivity values are considered

Table 3. Thickness of phreatic aquifer, hydraulic conductivity, transmissivity and effective porosity as obtained from available data.

Drainage parameter Lateral No.	Thickness of phreatic aquifer (m.)	Hydraulic conductivity (m./day)	Transmissivity ($m.^2$/day)	Effective porosity %
1	15.836	0.462	7.316	2.33
2	15.934	0.319	5.080	4.62
3	15.871	0.311	4.940	4.52
4	15.840	0.319	5.050	4.62
5	16.007	0.236	3.780	5.02
6	15.880	0.251	3.990	5.02
7	15.996	0.235	3.760	4.71
8	15.939	0.224	3.570	4.71
9	15.891	0.225	5.58	2.16
10	15.984	0.251	4.012	3.55

moderately slow in these clay soils. This may be caused by relatively wide spaced drains. This will be clarified later when discussing the drain spacing required. These findings can also be interpreted according to Fukada (1967). He reported that the surface soil becomes more permeable due to its cultivation where percolation of free water can only proceed to the base of the tilled layer, into which water can penetrate only through occasional wormholes , root channels, or vestiges of the summer fissures, thus resulting in a f·vourable effect for water table fall from the ground surface. The obtained hydraulic conductivity values using the auger hole method are given in Table 4. The average hydraulic conductivity was found to be 0.075 m./day. It is less than 10 cm/day which is considered a permeable soil according to the classification of Massland and Haskew (1958).

A comparison of hydraulic conductivity values obtained by processing the field drainage meaurements after 5 years from date of installation with those obtained by the auger hole method were carried out. The average hydraulic conductivity "K" as measured by the auger hole method was found to be 0.075 m /day, while it amounted to 0.283 m./day when calculated by processing data obtained from the same location according to Dieleman (1972). It is clear that the "K" as obtained by processing the drainage measurements is about 3.77 times the determined "K" by the auger hole method and this difference could be attributed to the different sample size of the two methods. The auger hole method gives the average "K" of the soil layers extending from water table to few centimeters below the bottom of the hole within a radius of about 0.5 m. while the "K" as calculated from the drainage data represents average values obtained from drained areas of 40 m. spacing about 125 m. length and that is in accord with Dieleman and Trafford (1976) and Martinez Beltran (1978).

3.7. Transmissivity "KD"

The ability of the aquifer to transmit water was calculated after processing the field drainage observations as shown in Table 3. The obtained "KD" values ranged from 3.57 to 7.316 m^2/day and the average KD is about 4.71 m^2/day. The

Table 4. The hydraulic conductivity values m./day as measured by the auger hole method.

Plot No.	hydraulic conductivity (m./day)
1	0.036 0.010
3	0.023 0.025
11	0.185
12	0.085
13	0.160

obtained data can be explained according to the suggestions of De Ridder et al. (1967) who decided that a fairly close relationship appears to exist between the geological structure and the transmissibility. He added that the lowest "KD" values are found where the aquiver is relatively thin, while the higher values are generally found on down-thrown blocks, where the aquifer is much thicker than on the up-thrown blocks.

3.7. Effective porosity "f"

Calculations were carried out for estimating values representing the effective porosity as presented in Table 3. The obtained effective porosity ranged from 2.33 to 5.02 % and the average "f" was found to be 4.13 %. The results are considered low according to Dieleman and Trafford (1976) who reported that 3 - 5 % (on volume basis) for heavy clays.

3.8 Flow resistance

To study the flow resistance, the total resistance W_{tot} was calculated by equation 12 and the obtained data are presented in Table 5. To facilitate the interpretation, total resistance was divided into horizontal, radial and entrance resistance.

Calculations from equation 13 were carried out to obtain the horizontal resistance "W_h" which ranged from 0.683 to 1.400 in the drained fields. This value is very low when considering D_0 = 15.70 m. which is 10 m (¼ L). The obtained results are in agreement with those of Van Beers (1965) who revealed that the horizontal resistance may be ignored if the depth of the impermeable layer exceeds (¼ L) and vica versa.

With respect to radial resistance, "W_r" was calculated from the field drainage observations using the equation of Ernst (1962) and it ranged from 3.180 to 6.569 as shown in Table 5. The average radial resistance was found to be 5.445 under 40 m. spacing and it is considered a high value. These findings are in accord with the results of Cavelaars (1974) who reported that these problems are entirely the result of using excessively wide drain spacings (up to 40 m.) which can be avoided by a proper drainage design.

Table 5. Total resistance, horizontal, radial and entrance resistance after processing the field drainage observations at 5 years from drains installation.

Drainage parameter Lateral No.	Total resistance (days/m.)	Horizontal rsistance (days/m.)	Radial resistance (days/m.)	Entrance resistance (days/m.)
1	4.928	0.683	3.180	1.065
2	7.143	0.984	4.612	1.547
3	7.298	1.013	4.727	1.558
4	7.140	1.000	4.606	1.534
5	9.657	1.324	6.241	2.092
6	9.071	1.254	5.858	1.959
7	9.692	1.330	6.266	2.096
8	10.174	1.400	6.569	2.205
9	10.099	1.398	6.535	2.166
10	9.074	1.253	5.859	1.962

Since, the entrance resistance "W_e" describes the water flow at entry into drain pipes, the field drainage observations were processed by using equation 15 for estimating values representing the entrance resistance shown in Table 5. The average entrance resistance was found to be 1.87 and it was considered higher than the criteria proposed by Dieleman and Trafford (1976) who reported that; if the entrance resistance was higher than 1.50 the drain line performance should be considered poor. Accordingly, the difficulty with which water flow through such clay soils is governed by its flow through and into drain entry however adequate the drain spacing may be.

3.9. Hydraulic head losses

It is necessary to know the total hydraulic head losses as shown in Table 6. A guide line to study all possible problems that can occur in tile drainage system is to divide the flow path into different stages and then the head loss in each stage could be measured.

The values represented in Table 6 point out that the hydraulic head loss in horizontal flow "h_r" in soil ranged from 6.72 to 14 cm. The average horizontal head loss as a fraction of the total head loss $(\frac{h_h}{h_{total}})$ was found to 0.138. The obtained results are considered high as a result of excessively wide drain spacings, Cavelaars (1974).

With respect to the radial hydraulic head loss "h_r" in the flow path adjacent to the drain, the results presented in Table 6 indicate that the radial head loss "h_r" values ranged from 30.95 cm to 62 cm. It is also observed that the radial hydraulic head loss was increased about 4.69 and 3.00 times the horizontal hydraulic head loss and the entrance head loss, respctively.

To facilitate studying the undesirable effect of radial hydraulic head loss on the efficiency of drainage systems, calculations were carried out to obtain radial hydraulic head loss as a fraction from the total hydraulic head loss, i.e. $\frac{h_r}{h_{tot}}$. Data presented in Table 6 reveal that the head

Table 6. The total, horizontal, radial and entrance head loss and their corresponding fractions from the total head loss after 5 years from drains installation.

Drainage Parameter Lateral No.	Total head loss cm.	Horizontal head loss cm.	Horizontal total head	Radial head loss cm.	Radial total head	Entrance head loss cm.	Entrance total head
1	96	13	0.135	62	0.646	21	0.219
2	80	11	0.138	52	0.650	17	0.213
3	58.38	8.10	0.139	37.82	0.648	12.46	0.213
4	47.98	6.72	0.140	30.95	0.645	10.31	0.215
5	90	12	0.133	58	0.644	20	0.220
6	53.7	7.4	0.138	34.7	0.646	11.6	0.216
7	88	12	0.136	57	0.648	19	0.215
8	70	10	0.143	45	0.643	15	0.214
9	82	11	0.134	53	0.646	18	0.215
10	98	14	0.143	63	0.643	21	0.214

loss fraction $\frac{h_r}{h_{tot}}$ ranged from 0.644 to 0.650 and the average was found to be 0.645. The obtained results are considered high due to the significant radial flow resistance to the drains as a result of using widely spaced drain , i.e. 40 m. These findings are in harmony with those obtained by Cavelaars (1974) and Dieleman and Trafford (1976).

The results obtained show that the head loss from streamlines towards the inlet "h_e" which constitutes the major part in the total hydraulic head loss in these clay soils is generally moderate in all drained fields as shown in Table 6. It is also observed that the head loss fraction $\frac{h_e}{h_{total}}$ ranged between 0.213 and 0.220. It was considered moderate by the criteria suggested by Dieleman and Trafford (1976) who reported that the performance of drain line could be considered moderate when the head loss fraction $\frac{h_e}{h_{tot}}$ ranged from 0.15 to 0.30.

3.10. Groundwater recharge, discharge and storage capacity

It is necessary to know the recharge of groundwater "R" which is divided in this study into: the discharge from groundwater "q" and the groundwater storage "S" as shown in Table 7. The results obtained reveal that the recharge to groundwater is variable from one drained field to another as a result of the variable of applied volume of irrigation water. The obtained data show also that any change in the recharge is reflected on both the discharge from groundwater and groundwater storage and that is also in accord with Ward (1967) who reported that, if recharge exceeds discharge, storage will increase.

To facilitate the interpretation of the discharge and storage, their values as percentages of their values in relation to the recharge were considered. Hence, the percentage $\frac{q}{R}$ x 100 and $\frac{S}{R}$ x 100 may be regarded as a general rough measure of the efficient working of the soil/artificial drainage systems as suggested by May and Trafford (1977). The reported data in Table 7 reveal that $\frac{q}{R}$ x 100 ranged between 45.3 % and 58 % while $\frac{S}{R}$ x 100 was found to be 42 - 54.7 %. These results reflect different problems of draining the clay soils where

Table 7. Recharge to groundwater, discharge, storage capacity and their corresponding percentages and drain spacing after processing the field drainage observations.

Drainage parameter lateral No.	Recharge mm/day	Discharge rate mm/day	Storage mm/day	Discharge recharge x 100	Storage recharge x 100	Required drain spacing (m.)
1	40.7	23.2	17.5	57	43	37.42
2	49.4	28.7	20.7	58	42	33.65
3	40.4	20.8	19.6	51.5	48.5	33.58
4	33.7	17.5	16.2	51.9	48.1	33.47
5	65.4	29.6	35.8	45.3	54.7	30.66
6	61.4	28.2	33.2	45.9	54.1	31.74
7	38.9	18.2	20.7	46.8	53.2	31.89
8	47.8	21.5	26.3	44.98	55.02	31.80
9	29.2	15.8	13.4	54.1	45.9	35.52
10	47.1	24.5	22.6	52	48	33.76

the storage exceeds the discharge. This may be due to the absence of proper design. The results obtained confirm that the water movement in such soils is almost entirely confined to the relatively disturbed soil of the tilled layer and the trench backfill.

3.11. Drain spacing required

The objective of this study was to provide high quality data, test fields that show which drain spacing was installed right or wrong and, present the reasons for it. Therefore, the drain spacing required was calculated from the collected field observations under non-steady state. The obtained drain spacings required by using the modified Glover and Dumm are given in Table 7. It is observed that drain spacings ranged from 30.66 to 37.42 m. and the average was found to be 33.35 m. The calculated drain spacings are lower than the actual by 16.63% as an average. Due to the extra spacing between laterals, the established sub surface drains at El Gemmeiza Farm are considered not functioning satisfactorily. This may be the result of absence of a proper design, including a proper determination or assessment of the hydraulic conductivity, effective porosity, the depth to the impervious layer, period of recharge and the days after cessation of the recharge.

4. Summary

Water flow takes place mainly as a horizontal flow in a more permeable top-layer. The relation between hydraulic head and discharge rate was found to be approximately constant at 2-5 days after cessation of recharge due to the fact that a part of the drainage water does pass through layers below drains.

The obtained values for the drainage intensity factor (a) is between 0.081-0.342 days^{-1}. The values are low as a result of the wide drain spacing used.

The depth of the impermeable layer (D_o) was found to be at 15.70 m from the drain level. The thickness of the equivalent layer (d) as calculated by processing the field drainage observations was found to be 2.80 m and it is almost the same as the tabulated (d) value obtained by Hooghoudt.

The hydraulic conductivity (K) as obtained by processing the field drainage observations is 0.283 m/day as an average, while it was 0.075 m/day when the hydraulic conductivity was measured by the auger hole method. The ontained (K) by processing the field drainage observations is about 3.77 times the determined (K) by the auger hole method. This difference could be attributed to the different size of zone under the two methods.

The obtained values for transmissivity were between 3.57 and 3.316 m^2/day as they are the product of hydraulic conductivity and thickness of the phreatic aquifer.

Effective porosity (f) was found to be between 2.33 and 5.02%.

The effect of horizontal resistance was low and may be ignored because the depth of the impermeable layer exceeds ¼ drain spacing. The radial resistance was found to be 5.44 and it is considered a high value. The entrance resistance was higher than the criteria proposed by Dieleman and Trafford.

Horizontal and radial hydraulic head losses were higher than the accepted values as a result of excessively wide drain spacing. The entrance head loss was not satisfactory.

Any change in the recharge to groundwater is reflected in both discharge from groundwater and groundwater storage.

The calculated spacing ranged from 30.66 to 37.42 m and an average of 33.35 m. This value (33.35 m) is lower than the actual (40 m) by 16.63%.

5. Recommendation

1. In arid and semi-arid areas where agriculture depends mainly on irrigation, drainage is a necessary complement to irrigation in areas where there is not adequate natural drainage.
2. No irrigation scheme should be considered without provision of drainage to insure continuing irrigated agriculture.
3. It is worthwhile to note that clogging in and around the tiles (or collectors,..) has become so serious that cleaning costs are too high to reestablish a functioning drainage system. Therefore, the present drainage system must be replaced to effect efficient drainage of the area.
4. According to the results obtained from collected data on the field drainage system, to obtain favourable soil-water-air relation, the drain spacing should be 30 m to obtain proper drainage.
5. From the obtained results, a filter (gravel is preferred) is needed for plastic tile system according to the classifications of USDA Soil Conservations Service (1971).
6. Due to inefficiency of El-Santa Drain, it is necessary to install a pump station to remove the drainage water from the collectors into El-Santa Drain canal by a secondary tile collector connecting ends of main collectors (1 km) parallel to El-Santa Drain.
7. Inspection chamber junctions (Fig. 25) are usually provided with a silt trap, the bottom of the chamber being some 30 cm below the bottom of the lowest pipe entering or leaving the chamber. It is advisable to have the laterals some 10 cm above the top of the collector to enable the discharge of the laterral to be inspected. The cover of the chamber may be above or below ground surface. Provided it is at sufficient depth not to interfere with

cultivation, placing it below surface is preferable because the chamber is then protected against damage and abuse (farmers sometimes use junction boxes as outlet for excess irrigation water).

8. The long term objective is to achieve a totally integrated research extension program on the area for optimizing crop production. This will serve a model for optimizing crop production throughout the A.R.E. as one of the contribution of EMCIP.

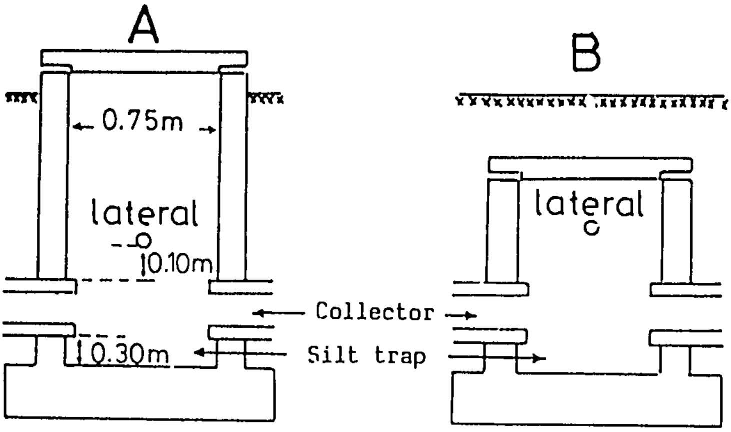

Fig: 25. Inspection chamber juctions between laterals and collectors.

A: Cover above ground surface

B: buried cover .

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