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PERFORMANCE EVALUATION OF THE SUBSURFACE DRAINAGE SYSTEM IN A DAKAHLIA REGION, EGYPT

تقييم أداء نظام الصرف المغطى بمنطقة بالدقهلية - مصر

By

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الخلاصة

تتناول هذه الدراسة تقييم أداء نظام الصرف المغطى في مساحة 30000 هكتار بالمشروع المتكامل لتحسين التربة والمياه بالدقهلية بدلتا النيل بمصر، حيث تم قياس معدلات الصرف من المجمعات و علاقتها بالانحدار الهيدروليكي و تذبذب منسوب سطح الماء الأرضي و الضاغط أعلى مستوى نظام الصرف. وقد اعتبرت هذه الدراسات الحقلية كمؤشرات للدلالة على أداء نظام الصرف، وتمت تلك القياسات خلال ثلاث مواسم زراعية هي صيف 1996 و شتاء 96-1997 و صيف 1997. أظهرت النتائج أن معدلات الصرف للمجمعات كانت أقل من المعدل التصميمي لها في معظم الأوقات عدا موسم الصيف بالأراضي المنزرعة جميعها بالأرز. كما دلت النتائج على أن معدل الصرف التصميمي للمجمعات و المعتمد على قياس الانحدار الهيدروليكي لا يعبر عن التصرف الفعلي في نظام الصرف، وأن الضاغط أعلى أنابيب المجمعات مرتفع فقط في موسم الصيف حيث عمق الماء الأرضي مناسب في أغلب الأوقات عدا المساحات المنزرعة أرزا أو المجاورة لأراضي منزرعة بالأرز. أما بالنسبة لتباعد الحقليات فكانت أقل من القيم التصميمية في موسم الشتاء و بالأراضي غير المنزرعة أرزا في موسم الصيف، ومع ذلك يتطلب زيادة تباعد الحقليات ليصل إلى 3-4 أمثال القيمة التصميمية في مناطق زراعة الأرز.

ABSTRACT

This study is conducted to evaluate the performance of subsurface drainage system in the 30000 hectares Integrated Soil and Water Improvement Project (ISAWIP) Dakahlia, Nile Delta, Egypt (ISAWIP, 1994). The drainage collectors rates and its relationship with collectors hydraulic gradient. The overpressure in the drainage system and the fluctuation of groundwater table were measured as indicators for the performance of the subsurface drainage system. Three cropping seasons, summer 1996, winter 1996-1997 and summer 1997 were considered. Results show that the drainage collectors rates are under the design one in most of the time except in summer season in the case of cultivation rice in majority of the area served by the drainage system. The collector drainage rate based on the measured hydraulic gradient did not represent the actual drained rate of the system and the overpressure in the collector pipes was observed in the summer season only. The groundwater table depths were acceptable most of the time except the areas cropped with rice or adjacent to rice fields. The lateral drain spacing was underestimated in both the winter season and in the non-rice fields of the summer season. However, the lateral spacing required to manage the rice cultivation was three to four times the designed spacing. Results, which were achieved, could be widely applied under similar conditions.

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Introduction

Subsurface drainage system is an efficient tool to remove excess water and salts from the soil profile to enhance crop growth. In Egypt, constrains of agriculture production are the very limited availability of agriculture land and the soil problems of water logging and salinization due to the perennial irrigation system after the construction of Aswan High Dam.

Design and construction quality or operation and maintenance conditions govern the performance of the existing drainage systems. The performance assessment of the existing drainage systems is required for evaluating design criteria and quality of construction, introducing rehabilitation programs if found necessary. Egypt is among the few developing countries, which implemented subsurface drainage systems on a large scale during the past half century. Performance of the implemented systems was always subjected to an assessment. In some cases the objective is to verify the design criteria (Abdel-Dayem and Ritzema, 1990) and in others, to determine the impact of subsurface drainage on water table levels, soil salinity and crop yield.

This paper introduces an attempt of evaluation for the sake of the performance of subsurface drainage systems in a specific part of the northeastern Nile Delta represented in the ISAWIP Project. The evaluation is a co-operation between the Egyptian government represented by the Drainage Research Institute and the Canadian government. This study depends on selecting a number of performance indicators based on the system's hydraulic parameters to determine the functionability of the subsurface drainage systems.

DESCRIPTION of THE ISAWIP PROJECT

The ISAWIP project was a joint undertaken by the Governments of Egypt and Canada designed to demonstrate how an integrated approach to agriculture development can effectively increase crop production in the old lands of the Nile Delta. Figure (1) shows the location of the project area in Dakahlia region.

The project, which was executed between 1989 and 1998, included concurrent execution of improvement drainage, irrigation, soil and agricultural extension. Modern technology was introduced in the design and construction procedure of the drainage systems as well as new drainage materials (ISAWIP, 1994).

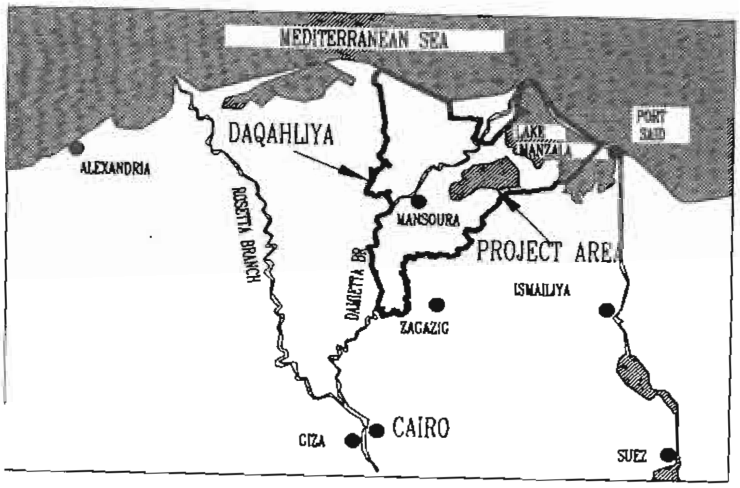


Figure (1) ISAWIP project location

Topography and Climate

The project area is almost flat with elevation ranges from four meters above sea level in the western part of the area to a few centimetres below sea level in the north-eastern part. Climate is predominantly Mediterranean with mean monthly temperature ranges between 11.9 °C and 26.6 °C, (Abu Zied, 1989). The average annual rainfall during the period 1974-1983 was 42 mm (ISAWIP, 1994).

Soils and Crops

The soil is predominantly fine textured with low permeability to depth between 20 m and 40 m, below which sand and gravel aquifer predominate. The fine textured layer is referred to as the clay-silt layer or the clay cap. The area is intensely cultivated with the principal winter crops being wheat, beans and berseem (Egyptian clover) and the summer crops being cotton, rice and maize which are usually combined in two or three year rotations. The cropping intensity is about 190% (ISAWIP, 1994).

Pre-Investigation Data

The basic information on which the decision of constructing a subsurface drainage system in the area was taken by the ISAWIP project team and was summarised as (ISAWIP, 1994):

(1) The percentage of the area with water table depth less than 50-cm varies between 10% and 40% depending on the time of the year. (2) The hydraulic conductivity (K) in the project area ranged from 0.001 m/day, to 3.74 m/day (measured at 2-m depth auger holes). (3) Average

depth of water table as measured at 3586 sites during the saturated hydraulic conductivity determinations was 0.66m ± 0.27 m. Only 5% of the area had a water table deeper than 1.2 m.

Subsurface Drainage Improvements

The design criteria were developed on the basis of integrating basic concepts field investigations, and the huge Egyptian experiences. The subsurface drainage system consists of lateral drains discharging into main and sub-collectors. The project was the first in Egypt to use the High-Density Ploy-Ethylene (HDPE) tubes. Previous projects used concrete collectors and PVC pipes.

Subsurface drainage design criteria could be summarised as: (1) Spacing between drain laterals was calculated using the full form of the Hooghoudt steady state equation; (2) Design water table depth was 0.85m; (3) Lateral drain depth was 1.4 m average, ranging from 1.25 m to 1.55 m; (4) Drain coefficient for lateral spacing was 1.5 mm/d and for collector design was 3.0 mm/d; (5) Effective drain radius was taken as the actual pipe radius (0.04m); (6) Drain envelop requirements thin synthetic fabric envelope; where the soil clay content < 30%, and if soil are alkaline (SAR >13) then envelop was used where the clay content is < 40%.

Methods and Materials

The study was carried out on a data of three seasons (May, 1996- Oct. 1997) to evaluate the performanee of subsurface drainage system, to verify the design criteria and to evaluate the impact of the drainage system on groundwater depth. The eight collectors serving an area of 200 hectare were chosen (two collectors per each contract of the total four project contracts). The areas of the chosen collectors had different soil properties, drain spacing, and drainage construction dates. Table (1) summarises the characteristics of the selected collectors.

Table (1) Characteristics of the selected evaluated areas

Collector No.	Date of installation	Area served Fed.	Collector pipe length (m)	Lateral pipe length (m)	Lateral spacing (m)
1	1991	39	850	2100	70
2	1991	70	2793	18751	20
3	1992	106	1049	14540	25
4	1992	21.5	464	3350	25
5	1994	94	1650	10920	35
6	1994	34.5	748	1260	35
7	1997	42	836	9400	20
8	1997	75.5	1236	17290	20

Discharges of collectors were measured at their outlets but no lateral discharges were measured because there were no laterals connected directly to maintenance manholes. The discharges were measured using calibrated bucket and stopwatch in case of free flow collector outlet and electronic pulse generator current meter in case of submerged outlet. Water table depth in the area of each collector was measured in a set of two row observation wells installed at one and two third across the lateral length. Each row had two observation wells installed at mid-spacing between parallel laterals and one observation well was above lateral drain. Each observation well reached 0.2 m below the lateral path (1.7 m below surface). The overpressure was measured at the collector manholes. It is defined as the height of water above the invert level of the inside perimeter of the outgoing collector pipe.

The evaluation of lateral spacing calculation was carried out using the falling water non-steady state Glover-Dumm equation, (ILRI, 1994) for the winter season and the non-rice summer crops as in equation (1). While, Kirkham Equation (Kirkham, 1957) was used for the ponding rice fields case, (equation, 2).

$$L = \pi\left(\frac{K d_e t}{f}\right)^{\frac{1}{2}}\left(\ln\frac{1.16h_0}{h_t}\right)^{\frac{-1}{2}} \qquad (1)$$

inwhich, L = drain spacing (m), K = hydraulic conductivity (m/d), d_e = equivalent depth of the soil layer below drain level (m), t = time after instantaneous rise of the water table (d), h_o = initial height of the water table at $t = 0$ (m), h_t = height of water table at time t (m), f = drainable pore space (porosity) and ln = natural logarithm.

The Glover-Dumm non-steady state equation would therefore be used in evaluating the laterals spacing by calculating the physical soil characteristics, which affect lateral spacing calculations. These characteristics are represented by the term Kd_e/f (Eq. 1) where; K is the saturated soil hydraulic conductivity, d_e is the equivalent depth of the impervious layer depth and, f is the soil drainable porosity. The term Kd_e/f was used to calculate the lateral spacing required to keep the groundwater level on a depth of 50 cm from soil surface after three days of irrigation then on a depth of 80 cm from soil surface after five days of irrigation.

$$q_l = \frac{4K}{L}\frac{(t_p + d - r)}{g_a} \qquad (2)$$

in which, q_l = the drain flow per unit drain length (m/d/m), t_p = the height of pounding surface (m), d = the drain depth (m), r = the drain radius (m), K = hydraulic conductivity (m/d), L =

drain spacing (m), and g_a = a function given by the following expression, (Abdel-Dayem and Eid, 1989):

$$g_a = 2\ln\frac{\sinh\pi\frac{(2d-r)}{L}}{\sin\pi\frac{r}{L}} - 2\sum_{n=1}^{\infty}(-1)^n n\ln\frac{\sinh 2\pi n\frac{D_i}{L} - \sinh\pi\frac{r}{L}}{\sinh 2\pi n\frac{D_i}{L} - \sinh\pi\frac{(2\pi-r)}{L}} \qquad (3)$$

where D_i = depth of impermeable layer (m).

Results and Analysis

The recent and suitable definition of the performance of sub-drainage system was the determination of the state of functioning of the drainage system compared with established design criteria and to identify the degree of malfunctioning (if existed), (Smedema and Vlotman, 1996).

Drainage Rate Ratio Indicator

The drainage rate ratio (q_{ratio}) is the percentage ratio between the cumulative frequency of non-exceeding collector discharge 90%, q_{90} and the designed drainage rate, q_{des}. The best drainage performance is when q_{ratio} equals 100% i.e. q_{90} equals q_{des}. However, when q_{ratio} is less than 100%, the collector is considered over designed and, when the q_{ratio} is greater than 100%, the collector is considered under designed. The q_{ratio} is defined as follows:

$$q_{ratio} = q_{90}/q_{des} \quad \% \qquad (4)$$

The q_{90} values for the three cropping seasons; summer 96, 97, and winter 96-97 are shown in figure (2). The q_{ratio} values for three cropping seasons of the years 1996 and 1997 are shown in table (2).

Table (2) Drainage indicator (drainage rate ratio, q_{ratio} %) of collectors

Coll. No	1	2	3	4	5	6	7	8
Summer 96	287	353	149	266	228	321	***	***
Winter 96-97	63	40	127	312	87	134	***	***
Summer 97	105	82	133	248	173	199	239	194

***Drains were not installed yet

It is noted that all drainage systems gave results of q_{ratio} greater than 100% during summer 1996. It is due to the increase in rice intensity and it is different from the design intensity that should not exceed 50% of the area served. In winter season 1996-97, the q_{ratio} for all collectors varied between 40% and 134%. The high q_{ratio} of 134% in collector 6 may be due to bad water management. In summer season 97, the indicator value q_{ratio} , of all collectors were greater than 100% except collector 2 which had a small rice cultivated area with an indicator value of 82%. The q_{ratio} values of the summer 97 were less than those of summer 96 since the area cultivated with rice was less in summer 97. The q_{ratio} evaluation showed that. the collector drains were under designed and their capacity were less than the actual drainage rate most of the time for this type of crop pattern except in the case of cultivation rice in majority of the area served by the drainage system.

Overpressure In Collector Pipes

Overpressure is defined as the height of water above the invert level of the inside perimeter of the outgoing collector pipe. In the design procedure of the drainage system, the hydraulic pressure line of the flow through collector pipes should coincide with the invert level of the pipes, or the hydraulic gradient equals the pipe's slope. An overpressure means that the gradient line was above the invert levels of the pipes and thus hinders the flow of the lateral drains. The average monthly and seasonal overpressure values at some collector manholes in the drainage systems are presented in table (3).

Table (3) Average seasonal overpressure in collector pipes in (m)

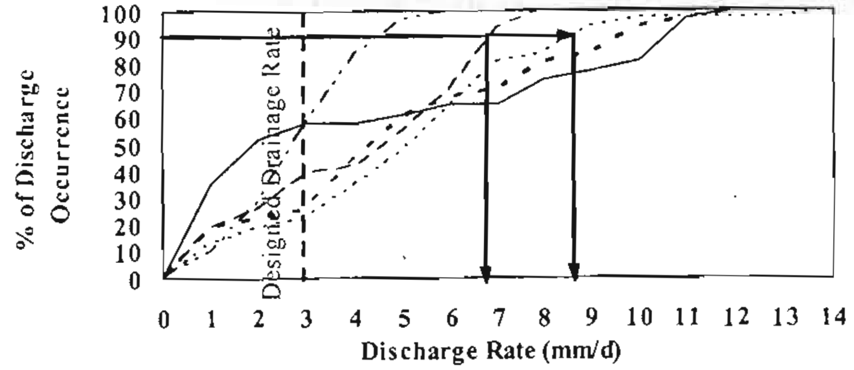
Collector No.	1		2		3		5		6	
Manhole No.	1	2	1	2	1	2	1	2	1	2
Winter 96-97	0.01	0.07	0.00	0.00	0.00	0.01	0.06	0.11	0.01	0.01
Summer 97	0.00	0.03	0.00	0.00	0.03	0.09	0.08	0.17	0.00	0.24

Collector No.	7			8			
Manhole No.	1	2	3	1	2	3	4
Winter 96-97	***	***	***	***	***	***	***
Summer 97	0.03	0.58	0.68	0.05	0.22	0.32	0.36

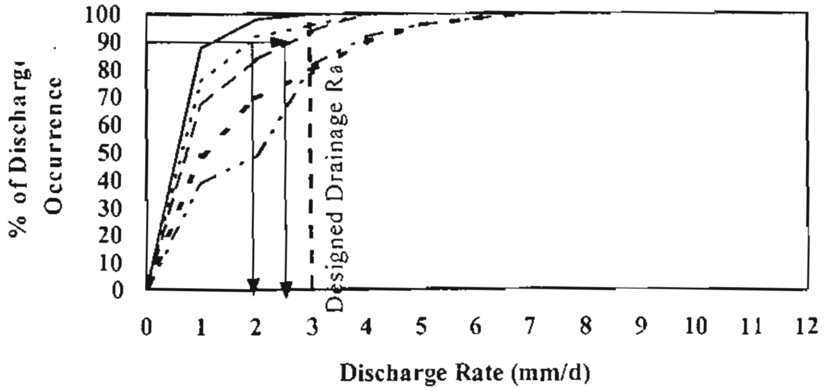
*** Drains were not yet installed

Generally, the overpressure was found in the summer season, (with maximum value of 0.68 m) as a result of the cultivation of rice in majority of the served area of drains while there was no overpressure in the winter season for most times. The overpressure values ranged from 0 to 0.10 m and that meat that the drainage systems were under designed and their capacity were greater than the actual drainage rate most of the time for this type of crop pattern. Only drainage system number 5 had remarkable overpressure values. It had a submerged outlet all the time and this submergence restricts the drainage system flow and raises water in the collector manholes.

(summer 96)



(winter 96-97)



(summer 97)

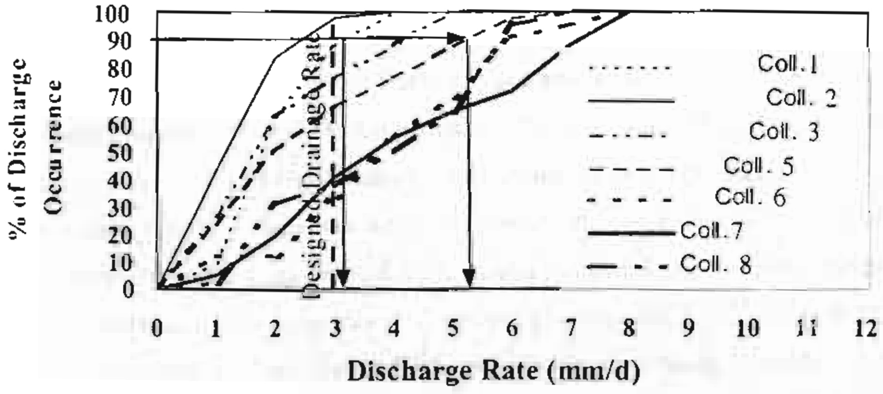


Figure (2) cumulative frequency of non-exceedance collector discharge

The overpressure values in both seasons were in a range of 0.06 to 0.17m. As for drainage systems 7, and 8, the overpressure was calculated only for the summer season 1997. The open drain water that submerged the collector outlets restricted the water flow in both systems. The overpressure was increased gradually in both collectors in the upstream direction as shown in table (3).

Groundwater Depth Evaluation

The primary aim of drainage is to control the water table in order to improve soil aeration and to enable timely farm operation. Two groundwater indicators were used to evaluate the performance of drainage system; the relative groundwater depth (RGWD), and the frequency of exceedance of groundwater within 85 cm below soil surface (F_{85}). Examples for the measured groundwater table depth compared with intended Design Water table Depth. (DWD) of 0.85 m, and the F_{85} of the drainage systems number 1, and 5 are presented in figures (3) and (4).

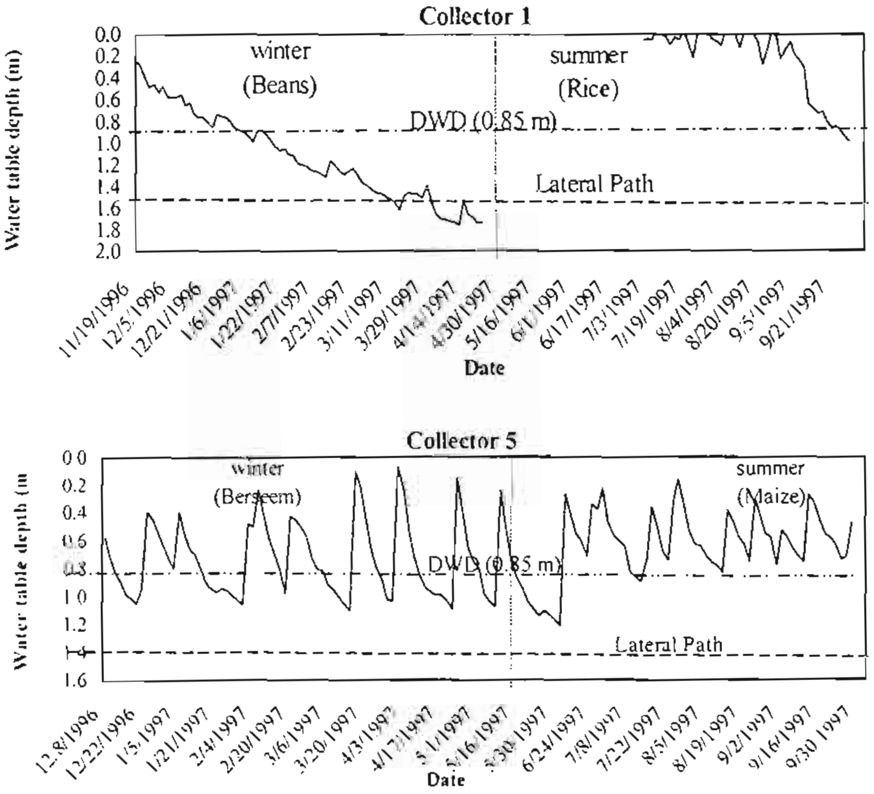


Figure (3) Average Ground Water Depth of Drainage Systems 1, and 5

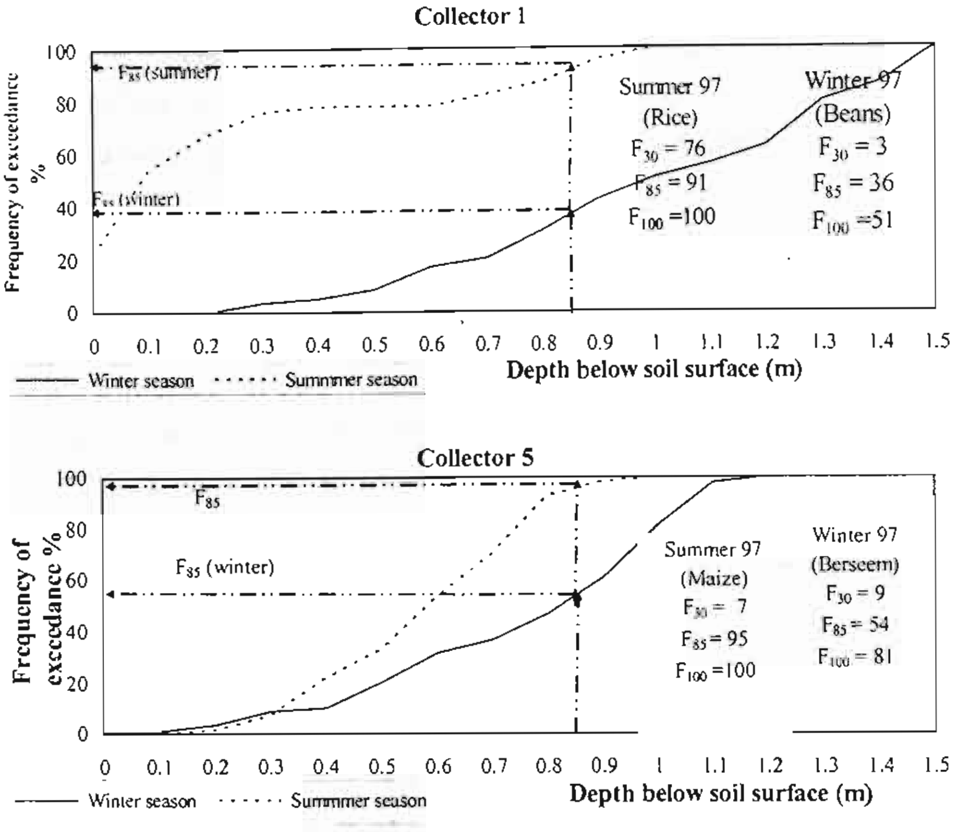


Figure (4) Frequency of exceedance of water table depth of drainage system 1, and 5

Relative Groundwater Depth (RGWD)

It is the ratio between the average depth to water table in a season and the intended depth to water table in the same season (0.85 m), Gupta et al.(1998), which is expressed by:

$$RGWD = \frac{\textit{Average depth to water table in the season}}{\textit{Intended depth to water table in the season}} \% \qquad (5)$$

For a well-designed and operated drainage system, the value of RGWD should be more than or equal 100%. A value greater than 100% would indicate real excess (over) drainage, while a RGWD value less than 100% would mean poor drainage. Computed values of RGWD for both winter and summer seasons are presented in table (4).

In the summer season 97, the RGWD values varied between 7% and 149%. This big difference is attributed to the crop that was cultivated in the observed part of the drainage system as well as the crops, which surrounds that studied part. In drainage, systems 1, 4, and 8 the RGWD in the rice fields are very low in a range of 7 and 26%. This means poor drainage condition took place because of the pounding rice cultivation. In drainage system 2, the RGWD value in the maize fields away from rice fields was 149%. This means an excess drainage (over drainage) in this field. While in drainage system No. 3, the maize was cultivated adjacent to small area cultivated with rice. Its RGWD value was 105% and this means the drainage system was well designed with crop pattern similar to the design one. On the other hand the rice area in drainage systems 5, and 7 were compared with drainage system 3. The RGWD in these systems were 67% in maize and cotton fields in drainage systems 5 and 7 respectively. The extra area of rice fields adjacent to maize and cotton field was the reason of poor drainage in systems 5, and 7.

Table (4) Relative Ground Water Depth (RGWD) of chosen parts in drainage systems

Coll.	Winter season 96-97			Summer season97		
No.	RGWD %	Crop	Performance	RGWD %	Crop	Performance
1	133	Beans	over drainage	27	Rice	poor drainage
2	126	Berseem	over drainage	149	Maize (1)	over drainage
3	124	Berseem	over drainage	105	Maize (2)	well designed
4	111	Berseem	over drainage	18	Rice	poor drainage
5	87	Berseem	poor drainage	67	Maize (2)	poor drainage
6	125	Berseem	over drainage	7	Rice	poor drainage
7	***	***	***	67	Cotton (2)	poor drainage
8	***	***	***	11	Rice	poor drainage

**** Drains were not installed yet   Maize (1) & (2) are Maize away from and adjacent to rice fields respectively*

Frequency of Exceedance of Groundwater

It is the percentage of times of occurrence of the water table depth at a 85-cm layer below the ground surface during the growing season. It is an indicator of the total duration the water table exists within the depth before it falls down below it. For a well-designed and operated drainage system, the value of F_{85} should be nearly 0%. A value less than 25% would indicate water stress on the deep root plants while, a F_{85} value in between 25% and 100% would indicate poor drainage or water logged root zone, (Rashed, 1998).

Values of F_{85} for both winter and summer seasons are presented in table (5). The frequency of occurrence of water table above 0.85m depth as a root zone, F_{85} is a good tool for the evaluation of the water table in the collector's area served. The F_{85} values were less than 50% during the winter season indicating a good environment for root zone aeration. While, in the summer season, the F_{85} values were 100% in rice fields and the other fields surrounding by rice fields. However, it was less than 50% for non-rice fields away from the rice fields.

Lateral Spacing Ratio

The spacing between laterals is one of the most essential parameters for the design of drainage systems. The right drain spacing is important in controlling the groundwater in the root-zone to enhance the aeration for crop growing. The performance of the drainage system is directly affected by the lateral spacing. The lateral spacing ratio (L_{ratio}) could be used as performance indicator for evaluating the designed lateral spacing with respect to different crops. It is the ratio between calculated (L_{cal}) and designed (L_{des}) lateral spacing. The L_{ratio} is expressed by:

$$Lratio = \frac{Lcal}{Ldes}\% \qquad (3)$$

Table (5) Cumulative frequency of occurrence (%) of ground water (F85)

Collector	**No.**	1	2	3	4	5	6	7	8
Winter 97	**F_{85}**	36	10	14	32	54	24	###	###
	Crop	Beans	Berseem	Berseem	Berseem	Berseem	Berseem	###	###
	Perf.	water stress on deep root plants	acceptable	acceptable	water stress on deep root plants	poor drainage	acceptable		
Summer 97	**F_{85}**	91	5	29	100	95	100	89	100
	Crop	Rice	Maize (1)	Maize (2)	Rice	Maize (2)	poor drainage	Cotton (2)	Rice
	Perf.	poor drainage	acceptable	water stress on deep root plants	poor drainage	poor drainage	poor drainage	poor drainage	poor drainage

Coll. 7,8 was installed on March 97. *Maize (1): Maize (away from rice fields)*
Maize (2): Maize (adjacent to rice fields)

The ideal lateral spacing is when L_{ratio} equals 100%. The low values of L_{ratio} are either an indicator of over estimated lateral spacing calculations in the design of the system or the existence of some sedimentation and misalignment in the laterals. But the cause of sedimentation and misalignment was not likely since the drainage systems was flushed just before the study and the pipes of the drainage systems were accurately laid using the laser technology. Table (6) presented the indicator L_{ratio} values for three cropping seasons.

Although, the Hooghoudt steady state equation was used in the design of lateral spacing, it was not suitable to be used in evaluating its performance. This was due to the difficulty of measuring lateral discharge in the field. The evaluation of lateral spacing calculation was carried out for each collector using the falling water non- steady state Glover-Dumm equation for winter 96-97 and summer 97 crops. Kirkham equation is used for rice fields in 96 and 1997 since there was a constant amount of water pounding above these fields.

In case of pounding rice, which representing the case where all the collectors were existing in summer, 96 and collectors 1, 4, 6, and 8 in summer 97, the calculated lateral spacing, L_{cal} is greater than L_{des} (table 6). The indicator values L_{ratio} varied from 331% and 491% in summer, 96 and are varied from 326% to 474% in summer, 97. This meant that the design lateral spacing was not feasible for cultivating rice consequently, the collector discharges was increased than that of the designed collector discharge rate as discussed before. Therefore, the lateral spacing needs to be enlarged for managing the irrigation in rice fields. For example, in summer, 96 the L_{des} value of collector 1 was 70m and the required to manage the rice cropping, L_{cal} was 303m, which means a poor field water management due to the narrow lateral spacing.

Table (6) Designed and calculated lateral spacing and its indicator (L_{ratio})

Coll. No.	L_{des} (m)	Summer 96			Winter 96-97			Summer 97		
		L_{cal}	L_{ratio}	Crop	L_{cal}	L_{ratio}	Crop	L_{cal}	L_{ratio}	Crop
1	70	303	433	Rice	62	88	Beans	298	426	Rice
2	20	98	491	Rice	29	146	Berssem	11	56	Maize
3	25	83	331	Rice	22	90	Berssem	19	76	Maize
4	25	83	331	Rice	14	56	Berssem	82	326	Rice
5	35	142	404	Rice	20	58	Berssem	27	77	Maize
6	35	158	453	Rice	20	58	Berssem	158	453	Rice
7	20	***	***	***	***	***	***	14	68	Cotton
8	20	***	***	***	***	***	***	95	474	Rice

**** Drainage systems No. 7 and8 were not installed yet.*

$L_{Ratio} = L_{cal} / L_{des}$ %

In the winter season, the L_{cal} values of collectors 1-6 were smaller than L_{des} or in other words, the L_{ratio} was less than 100% in a range of 56-90% except for collector 2 that had a L_{ratio} value of 146%. This variation between L_{cal} and L_{des} might be due to a difference between the actual and the considered design parameters such as hydraulic conductivity, K or the depth of equivalent depth to the impervious layer, d_e. The L_{ratio} was considered good in collector 1 and 3 (88, and 90% respectively). That means the K and the d_e values were close in measured and designed cases. However, in collector 2 the L_{ratio} was 146% where L_{cal} is 29 meter greater than L_{des} that was 20 meter due to the over estimation of K and d_e as input data in the steady state design equation.

For the summer season, 97 (maize and cotton fields), the L_{ratio} was less than 100% or the L_{cal} values were smaller than L_{des} in a L_{ratio} range varied from 33 to 90% in collectors 1. and 8 respectively. This difference might be due to higher considered designed values for K than that of the actual measured values or shallower equivalent depth, d_e layers. Collectors 4, and 8 had good L_{ratio} values (88, and 90 % respectively) while, collectors 1 and 2 had poor L_{ratio} values (33, and 56% respectively).

Conclusions

The following conclusions may be outlined from the presented study:

1. The overall evaluation of the subsurface drainage systems with respect to the collectors drainage rates was that, the drainage rate values were generally acceptable in the winter season while in the summer season; they were not acceptable due to cultivation of rice in major parts of the served area of the drainage systems.
2. Generally, the overpressure was found in the summer season because of the cultivation of rice in majority of the served area of drains, while there was no overpressure in the winter season.
3. Measuring the overpressure in the drainage system was useful in evaluating the performance of the drainage system especially in the case of measured pressure head higher than that of the invert level of the collector pipes. It was also useful in discovering blocking, clogging, or a broken pipe in the system.
4. The relative groundwater depth indicator (RGWD) was a good indicator to evaluate the effect of the groundwater on the root-zone after installing the drainage system.
5. The frequency of occurrence of water table within 0.85-m depth as a root zone, F_{85} was a good tool for evaluating the water table of the collector's area served. The F_{85} values were less than 50% during the winter season indicating a suitable environment for root zone aeration. In the summer season, the F_{85} values were 100% in rice fields and the other fields surrounded by rice fields. However, it was less than 50% for non-rice fields away from the rice fields.

6. The lateral spacing ratio, L_{ratio} (L_{ca}/L_{des}) could be used as an indicator for the evaluation of the lateral spacing. Lateral spacing was generally underestimated for the winter season with ranges from 56 to 88%. In the summer season, L_{ratio} indicated that, the required lateral spacing was 3~5 times the designed spacing.

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