Spread Sheets for Laterals Spacing Design, With an Application on Mit Kenana Area in Egypt

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ABSTRACT

In this paper, Microsoft Excel software, as instance for spread sheets, is employed to get the laterals spacing design of steady state subsurface drainage systems. The most suitable and popular Hooghoudt equation is used to get the spacing L, including the equivalent depth. Given data are depth to the impermeable layer, radius of the pipe lateral, hydraulic conductivities of the soil above and below drain level, elevation of the water table midway between the drains, and drainage rate. Then, the lateral spacing L is assumed. Calculations are done through the spread sheet and the final result of L is obtained. Check for the obtained L is established with respect to the assumed value. Also, another check is employed for the equivalent depth d_e.
Mit Kenana area, 40 km North of Cairo, represents the eastern fringes of the Nile Delta in Egypt. Existing design of Mit Kenana area is reviewed. Then spread sheets are employed to obtain laterals spacing, which is referred to as spread sheet design. Almost identical results are accomplished by spread sheet design compared with the existing design.
Laterals spacing design for steady state subsurface drainage systems employing spread sheets is efficient, accurate, quick, easy and simple.

Keywords: *spread sheets, subsurface drainage, steady state, laterals, equivalent depth.*

1. INTRODUCTION

Agricultural drainage is defined as the removal of excess gravitational water from agricultural lands for crop production purposes. Agricultural drainage is generally divided into two categories, surface drainage and subsurface drainage. Surface drainage removes water from the soil surface by promoting gravitational flow overland and through channels to be collected and conveyed to an outlet. Subsurface drainage removes excess soil water to gravity or a pumped outlet [1].
Water available to plants is held in soil by capillarity, while excess water flows by gravity into drains. For subsurface drainage, laterals (field drains) are used to control the depth of the water table in the root zone by removing excess groundwater [2].

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For cropped irrigated and rainfed lands of the world, only about 14% is provided by some type of drainage. About 300 million ha, mainly in the arid and tropical humid zones of the developing countries, needs artificial drainage. Till the year 2030, drainage should be improved in at least 10 -15 million ha, which might require investing at least € 750 million annually. It is expected that one third of this area will be provided with subsurface drainage systems [3].

In this paper, Microsoft Excel software, as instance for spread sheets, is employed to get the laterals spacing design of steady state subsurface drainage systems. The most suitable and popular Hooghoudt equation is used to get the laterals spacing, including the equivalent depth. Spread sheets are formulated to obtain laterals spacing design of steady state subsurface drainage systems.

Also, Mit Kenana area in Egypt is studied, and its subsurface drainage system is referred to as existing design. Then spread sheets are applied to Mit Kenana area to obtain laterals spacing, which is referred to as spread sheets design. Both existing design and spread sheets design are presented and discussed.

2. LATERALS SPACING DESIGN OF STEADY STATE SUBSURFACE DRAINAGE SYSTEMS

The movement of water into the drains is mainly affected by the hydraulic conductivity of the soil and drain spacing, depth, and size. Hooghoudt equation, as shown in figure 1, is still the most suitable and popular equation for drainage design [4].

For steady state condition, the rate of recharge to the aquifer is assumed to be steady and equals the discharge of the drain. So, the water table position does not change as long as the recharge continues [5].

$$Q\,L^2 = 8\,K_b\,(D_i - D_d)\,(D_d - D_w) + 4\,K_a\,(D_d - D_w)^2 \quad \text{...} (1)$$

<u>Where:</u>

Q = steady state drainage discharge rate (m/day)
L = spacing between the drains (m)
K_b = hydraulic conductivity of the soil below drain level (m/day)
d_e = equivalent depth, a function of L, (D_i-D_d), and r
D_i = depth of the impermeable layer (m)
D_d = depth of the drains (m)
D_w = steady state depth of the water table midway between the drains (m)
K_a = hydraulic conductivity of the soil above drain level (m/day)
r_0 = drain radius (m)

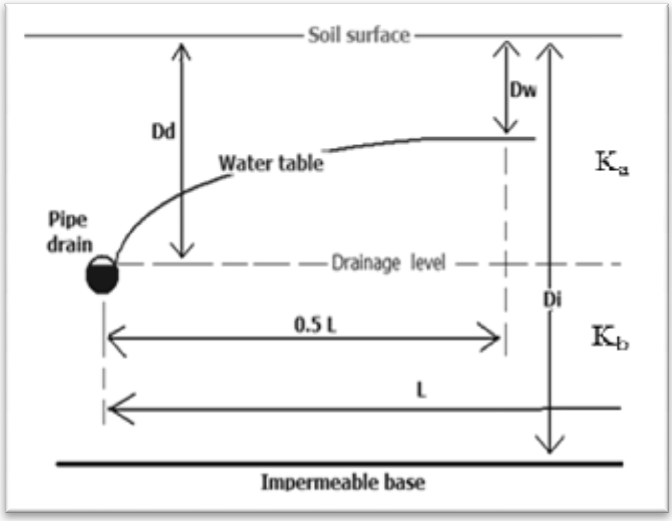

Fig. 1. Hooghoudt equation

To account for the extra head loss due to radial flow to the drains, two simplifications were followed in Hooghoudt theory. The first was assuming an imaginary impervious layer above the real one, which decreases the thickness of the layer through which the water flows towards the drains. The second was treating horizontal and radial flow to drains as an equivalent flow to imaginary ditches with their bottoms on an imaginary impervious layer at a reduced depth. In other words, the equivalent depth (d_e) represents an imaginary thinner soil layer through which the same amount of water will flow horizontally per unit time as in the actual situation. In equation 1, replacing the term (D_i - D_d) by (d_e),

$$Q\,L^2 = 8\,K_b\,d_e\,(D_d - D_w) + 4\,K_a\,(D_d - D_w)^2 \quad \text{..........(2)}$$

To determine the equivalent depth, a relationship was derived by Hooghoudt between the equivalent depth (d_e), the spacing (L), the depth to the impervious layer (D_i - D_d), and the radius of the drain (r_0). To simplify this relationship, tables were established for the most common sizes of drain pipes, from which the equivalent depth (d_e) can be attained.
Exact solutions for the equivalent depth required for Hooghoudt equation can be calculated from the following two equations, where D = (D_i - D_d) [6].

For D<L/4, $$de = \frac{D}{\frac{8}{\pi}\frac{D}{L}\ln\frac{D}{\pi r_0}+1} \quad \text{..........(3)}$$

For D>L/4, $$de = \frac{\pi L}{8\ln\frac{L}{\pi r_0}} \quad \text{..........(4)}$$

Many attempts were done to calculate the equivalent depth in order to get the laterals spacing for the subsurface drainage systems. Chieng et al [7], introduced some graphs for the equivalent depth versus the depth to impermeable layer for a range of pipe sizes and spacing between laterals.
A drain spacing formula has been derived considering the variation in flow and the area above the drain level in the radial flow zone [8]. The extent of radial flow zone is found to be 2/π times the thickness of soil layer below the drains. Hooghoudt equation based on equivalent depth is accurate enough to be used for drain spacing, but the computed water

surface profile in the radial flow zone differs considerably from that computed by the new method.

3. SPREAD SHEETS FOR LATERALS SPACING DESIGN OF STEADY STATE SUBSURFACE DRAINAGE SYSTEMS

Spread sheets are efficient, accurate, and simple way that can be applied to solve many issues in hydraulics and water resources. For instance, Microsoft Excel software, as a common popular spread sheet, was employed to get the best hydraulic trapezoidal sections for open channels with different side slopes [9]. Also, an additional solution was obtained concerning the velocity of water through the trapezoidal best hydraulic sections.

In this paper, Microsoft Excel software, as instance for spread sheets, is employed to get the laterals spacing design of steady state subsurface drainage systems. Equation 2 is used to get the spacing L, substituting by equation 3 to obtain the equivalent depth.

For the hypothetical case shown in table 1, given data are D, r_0, K_a, K_b, h and Q, where:

D: depth to the impermeable layer, (D_i - D_d), m
r_0: radius of the pipe lateral, m
K_a: hydraulic conductivity of the soil above drain level, m/day
K_b: hydraulic conductivity of the soil below drain level, m/day
h: elevation of the water table midway between the drains, (D_d - D_w), m
Q: drainage rate, m/day

Then, the lateral spacing L is assumed. Calculations are done through the spread sheet and the final result of L is obtained. Check for the obtained L is established with respect to the assumed value. Also, another check is employed for the equivalent depth d_e, where $D/L < 0.25$ as stated in equation 3.

As shown in table 1, the depth to impermeable layer (D) is 2.5 m, the lateral pipe radius (r_0) is 0.1 m, hydraulic conductivities of the soil above and below drain level (K_a and K_b) are the same with the value of 1 m/day, elevation of the water table midway between the drains (h) is 0.2 m, and drainage rate (Q) is 0.001 m/day.

It is assumed first that the lateral spacing ($L_{assumed}$) is 50 m. Then calculations through the spread sheet obtain a value of 58.29 m for the spacing (L) with 16.5% difference with respect to the assumed value. Other values are assumed for L till difference with respect to the assumed value becomes close to zero. Thus the spread sheets design for lateral spacing is 59 m, with only 0.19% difference with respect to the assumed value. Also the check for the equivalent depth (d_e) is satisfied, where the value of D/L is less than 0.25.

Table 1. Spread sheet for laterals spacing design of steady state subsurface drainage systems

Given	**D,** m	2.5	2.5	2.5	2.5	2.5
	r_0, m	0.1	0.1	0.1	0.1	0.1
	K_a, m/day	1	1	1	1	1
	K_b, m/day	1	1	1	1	1
	h, m	0.2	0.2	0.2	0.2	0.2
	Q, m/day	0.001	0.001	0.001	0.001	0.001
Assumed	***Lassumed,*** m	50	55	58	59	60
Calculated		25	25	25	25	25
		3.218875	3.218875	3.218875	3.218875	3.218875
		8.208133	8.208133	8.208133	8.208133	8.208133

		4.708133	4.708133	4.708133	4.708133	4.708133
		0.235406	0.214006	0.202936	0.199497	0.196172
		1.235406	1.214006	1.202936	1.199497	1.196172
	d$_e$, m	2.023625	2.059297	2.078247	2.084206	2.09
		0.16	0.16	0.16	0.16	0.16
		3.237800	3.294876	3.325195	3.334730	3.344000
		3.397800	3.454876	3.485195	3.494730	3.504000
		3397.800	3454.876	3485.195	3494.730	3504.000
Results	**L,** m	58.2906	58.77819	59.03554	59.11624	59.19459
	Check L	16.5813	6.869449	1.785421	0.197028	-1.34234
	Check de	0.05	0.045454	0.043103	0.042372	0.041666

Check L = ((L-Lassumed)/Lassumed)*100 Check de: D/L < 0.25

4. MIT KENANA AREA IN EGYPT

In Egypt, 100% of cropped area is irrigated, while 88% of this area is drained [10]. Annually, about 63,000 ha are provided by new subsurface drainage systems while old drainage systems are rehabilitated in about 12,600 ha. A scheme of the employed subsurface drainage systems in Egypt is shown in figure 2.

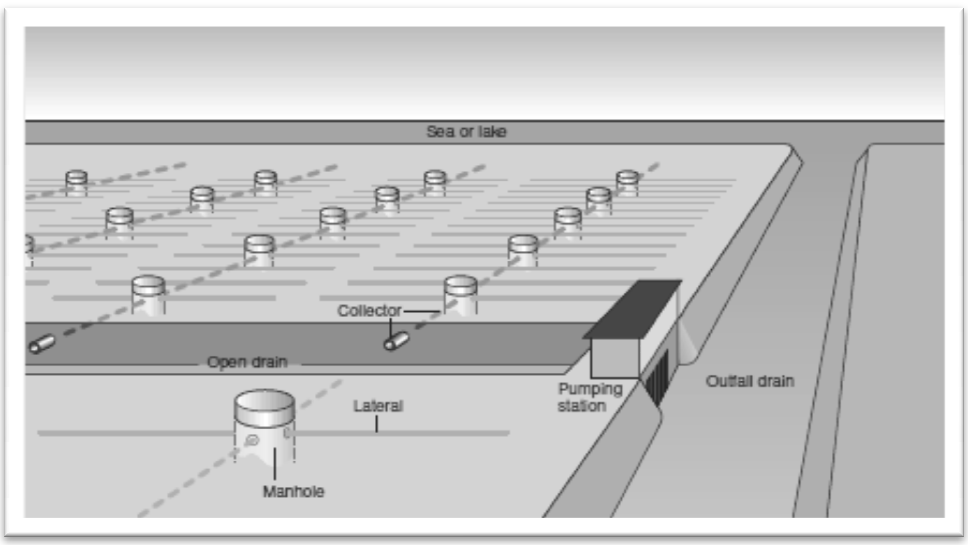

Fig. 2. Scheme of subsurface drainage systems in Egypt

Mit Kenana area is located about 40 km North of Cairo [11] and it represents the eastern fringes of the Nile Delta. It is 830 feddan (350 ha), with a main irrigation and drainage infrastructure, as shown in figure 3. The soils in the area consist of three layers. The third layer is considered impermeable layer as it has a hydraulic conductivity less than one tenth of that of the second layer. The hydraulic conductivity of the two upper layers is constant through the area with a value of 3 m/day.

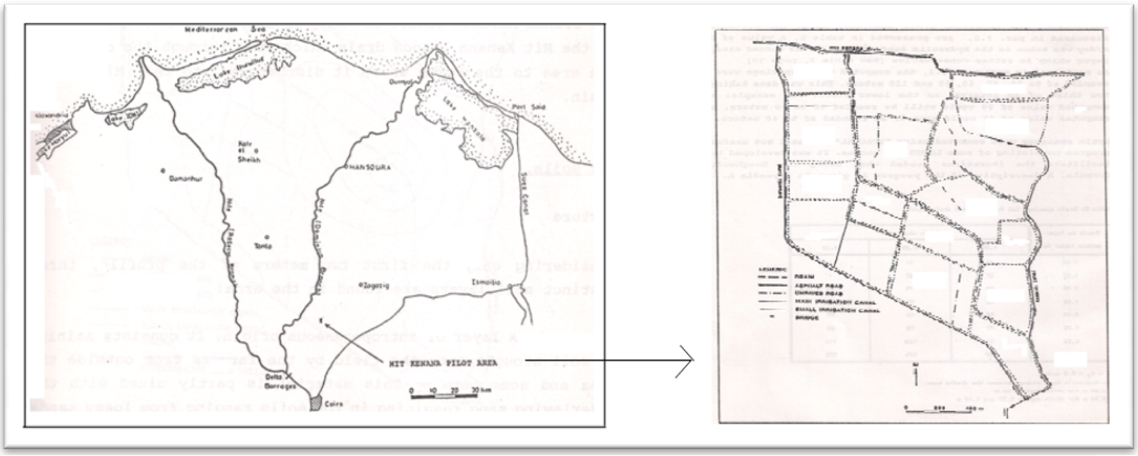

Fig. 3. Mit Kenana area in Egypt

The area is divided into sectors according to the depth to the impermeable layer (D_i), as shown in figure 3. The drain depth (D_d) is 1.2 m in a major part of the area due to limitations of topography and water level in the open drain. In some parts the drain depth has the values of 1.0 m and 1.4 m.

The values for water table depth (D_w) are 0.8 m, 0.9 m and 1.1 m.

The drainage rate (Q) is 0.0015 m/day.

The lateral spacing design is established and the subsurface drainage system is accomplished for Mit Kenana area [11]. This design is referred to as existing design in this paper.

For the Nile Delta in Egypt, including Mit Kenana area, the water table depth of 0.8 m achieves good conditions for the cultivated crops [12]. Also, the drainage rate of 0.0012 m/day is acceptable.

5. SPREAD SHEETS FOR LATERALS SPACING DESIGN OF MIT KENANA AREA IN EGYPT

Spread sheets are employed to obtain laterals spacing for Mit Kenana area, which is referred to as spread sheets design. Twenty two different laterals spacing designs are calculated according to the data of Mit Kenana area. These designs are included in table 2. Also, three spread sheets designs are shown in tables 3, 4 and 5 as samples for this technique.

Table 2. Spread sheets design of laterals spacing for Mit Kenana area

Depth of Impermeable Layer (D_I), m	Laterals Spacing, m		
	D_d=1.0 m, h=0.2 m	D_d=1.2 m, h=0.3 m	D_d=1.4 m, h=0.3 m
1.20	31	34	---
1.35	37	38	---
1.70	50 *	55	46
1.80	52	59	51 *
2.00	58	66	59
3.00	77	93	88
4.50	97	119	116
10.00	137	174	172 *

* Spread sheets that obtained these results are shown in tables 3, 4 and 5

Table 3. Spread sheets design, depth of impermeable layer is 1.7 m, drain depth is 1.0 m, and elevation of the water table midway between the drains is 0.2 m

Given	**D,** m	0.7	0.7	0.7	0.7
	r_0, m	0.1	0.1	0.1	0.1
	K_a, m/day	3	3	3	3
	K_b, m/day	3	3	3	3
	h, m	0.2	0.2	0.2	0.2
	Q, m/day	0.0015	0.0015	0.0015	0.0015
Assumed	**L*assumed,*** m	30	49	50	51
Calculated		7	7	7	7
		1.9459101	1.9459101	1.9459101	1.9459101
		4.9620709	4.9620709	4.9620709	4.9620709
		1.4620709	1.4620709	1.4620709	1.4620709
		0.034115	0.0208867	0.020469	0.0200676
		1.034115	1.0208867	1.020469	1.0200676
	d_e, m	0.6769073	0.6856784	0.6859591	0.686229
		0.48	0.48	0.48	0.48
		3.2491551	3.2912564	3.2926037	3.2938992
		3.7291551	3.7712564	3.7726037	3.7738992
		2486.1034	2514.171	2515.0691	2515.9328
Results	**L,** m	49.86084	50.141509	50.150465	50.159075
	Check L	66.202801	2.3296107	0.3009301	-1.6488724
	Check de	0.0233333	0.0142857	0.014	0.0137255

Check L = ((L-Lassumed)/Lassumed)*100

Check de: D/L < 0.25

Table 4. Spread sheets design, depth of impermeable layer is 1.8 m, drain depth is 1.4 m, and elevation of the water table midway between the drains is 0.3 m

Given	**D,** m	0.4	0.4	0.4
	r_0, m	0.1	0.1	0.1
	K_a, m/day	3	3	3
	K_b, m/day	3	3	3
	h, m	0.3	0.3	0.3
	Q, m/day	0.0015	0.0015	0.0015
Assumed	**L*assumed,*** m	50	51	52
Calculated		4	4	4
		1.3862944	1.3862944	1.3862944
		3.5350506	3.5350506	3.5350506

		0.0350506	0.0350506	0.0350506
		0.0002804	0.0002749	0.0002696
		1.0002804	1.0002749	1.0002696
	d$_e$, m	0.3998879	0.3998901	0.3998922
		1.08	1.08	1.08
		2.8791927	2.8792085	2.8792237
		3.9591927	3.9592085	3.9592237
		2639.4618	2639.4723	2639.4825
Results	**L,** m	51.375692	51.375795	51.375894
	Check L	2.7513849	0.7368532	-1.2002041
	Check de	0.008	0.0078431	0.0076923

Check L = ((L-Lassumed)/Lassumed)*100 Check de: D/L < 0.25

Table 5. Spread sheets design, depth of impermeable layer is 10.0 m, drain depth is 1.4 m, and elevation of the water table midway between the drains is 0.3 m

Given	**D,** m	8.6	8.6	8.6	8.6
	r$_0$, m	0.1	0.1	0.1	0.1
	K$_a$, m/day	3	3	3	3
	K$_b$, m/day	3	3	3	3
	h, m	0.3	0.3	0.3	0.3
	Q, m/day	0.0015	0.0015	0.0015	0.0015
Assumed	**L*assumed,*** m	90	155	172	173
Calculated		0.3142857	0.3142857	0.3142857	0.3142857
		27.363636	27.363636	27.363636	27.363636
		3.309215	3.309215	3.309215	3.309215
		0.2432323	0.1412317	0.1272727	0.126537
		0.8049081	0.467366	0.4211728	0.4187383
		1.8049081	1.467366	1.4211728	1.4187383
	d$_e$, m	4.7647857	5.8608419	6.0513401	6.061724
		1.08	1.08	1.08	1.08
		34.306457	42.198062	43.569648	43.644413
		35.386457	43.278062	44.649648	44.724413
		23590.971	28852.041	29766.432	29816.275
Results	**L,** m	153.59353	169.85889	172.52951	172.6739
	Check L	70.659473	9.5863784	0.3078554	-0.1884978
	Check de	0.095556	0.055484	0.05	0.049711

Check L = ((L-Lassumed)/Lassumed)*100 Check de: D/L < 0.25

6. RESULTS AND DISCUSSION

Three samples for spread sheets design are illustrated in tables 3, 4 and 5. For each table, given data are the depth to impermeable layer ($D = D_l - D_d$), the lateral pipe radius (r_0 = 0.1 m), hydraulic conductivities of the soil above and below drain level ($K_a = K_b$ = 3 m/day), elevation of the water table midway between the drains (h), and drainage rate (Q = 0.0015 m/day). The values of (D) and (h) are varying according to the location within the area.

The lateral spacing is assumed first ($L_{assumed}$), then calculations through the spread sheet obtain another value for the spacing (L). The percentage difference between (L) and ($L_{assumed}$) with respect to ($L_{assumed}$) is done to check (L). Other values are assumed for (L) till the difference becomes close to zero.

Also the check for the equivalent depth (d_e) is satisfied, where the value of (D/L) has to be less than 0.25.

As shown in tables 3 and 2, depth to impermeable layer (D) is 0.7 m ($D = D_l - D_d$ = 1.7 – 1.0). It is assumed first that the lateral spacing ($L_{assumed}$) is 30 m. After calculations through the spread sheet, the required spacing is 50 m with only 0.3% difference with respect to the assumed value. The check for the equivalent depth (d_e) is satisfied, where the value of (D/L) is 0.014 (less than 0.25).

Similarly, as shown in tables 4 and 2, depth to impermeable layer (D) is 0.4 m ($D = D_l - D_d$ = 1.8 – 1.4). It is assumed first that the lateral spacing ($L_{assumed}$) is 50 m. After calculations through the spread sheet, the required spacing is 51 m with only 0.7% difference with respect to the assumed value. The check for the equivalent depth (d_e) is satisfied, where the value of (D/L) is 0.0078 (less than 0.25).

Finally, as shown in tables 5 and 2, depth to impermeable layer (D) is 8.6 m ($D = D_l - D_d$ = 10.0 – 1.4). It is assumed first that the lateral spacing ($L_{assumed}$) is 90 m. After calculations through the spread sheet, the required spacing is 172 m with only 0.3% difference with respect to the assumed value. The check for the equivalent depth (d_e) is satisfied, where the value of (D/L) is 0.05 (less than 0.25).

Existing design of Mit Kenana area is reviewed according to the design data. Both existing design and spread sheets design are tabulated in tables 6, 7 and 8.

Table 6. Existing and spread sheets design for laterals spacing
[Drain Depth (D_d) = 1.0 m & Elevation of water table midway between drains (h) = 0.2 m]

Depth of Impermeable Layer (D_l), m	Laterals Spacing, m	
	Existing Design	Spread Sheet Design
1.20	30	31
1.35	37	37
1.70	50	50
1.80	52	52
2.00	58	58
3.00	77	77
4.50	97	97
10.00	137	137

Table 7. Existing and spread sheets design for laterals spacing
[Drain Depth (D_d) = 1.2 m & Elevation of water table midway between drains (h) = 0.3 m]

Depth of Impermeable Layer (D_l), m	Laterals Spacing, m	
	Existing Design	Spread Sheet Design
1.20	34	34
1.35	37	38

1.70	55	55
1.80	59	59
2.00	66	66
3.00	93	93
4.50	120	119
10.00	174	174

Table 8. Existing and spread sheets design for laterals spacing
[Drain Depth (D_d) = 1.4 m & Elevation of water table midway between drains (h) = 0.3 m]

Depth of Impermeable Layer (D_I), m	Laterals Spacing, m	
	Existing Design	Spread Sheet Design
1.70	46	46
1.80	50	51 *
2.00	59	59
3.00	88	88
4.50	116	116
10.00	172	172 *

As shown in table 6, eight different laterals spacing designs are calculated according to the data of Mit Kenana area. Similarly, table 7 includes eight different laterals spacing designs. Finally, table 8 contains six different laterals spacing designs.
From these results, it can be seen that both existing design and spread sheets design are almost identical with negligible differences in limited designs.

7. CONCLUSIONS

Laterals spacing design for steady state subsurface drainage systems employing spread sheets is efficient, accurate, quick, easy and simple. It can be widely used to get the required spacing between the laterals (field drains). Applying this technique on Mit Kenana area in Egypt obtained almost identical results compared with the existing design. This technique can be applied to get the laterals spacing design quickly and accurately. It can be also used to obtain efficiently the equivalent depth for steady state subsurface drainage systems.

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