COST ANALYSIS FOR SPRINKLER IRRIGATION SYSTEM

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ABSTRACT

Sprinkler irrigation is one of the efficient irrigation systems. The system layout simply consists of main line, submain, manifolds and laterals. There are many possible alternatives for the system layout. The main problem facing the designer is the choice of optimum system layout which depends on several factors. One of these factors is the assessment of capital cost of pipelines which mainly affects the total cost of the system. The second factor is the assessment of total friction losses of the system which mainly affects not only the pump head but also the pump cost.

Mostafa [7] presented "cost analysis for drip irrigation system". The paper, herein, presents a cost analysis for sprinkler irrigation system. Several alternative layouts for a square cultivated area up to 150 Feddan are presented. Friction head loss analysis is performed for each layout. Comparison is done to show the layout which has a minimum friction head loss. Also, cost analysis of pipeline system is performed to show the layout which has a least capital pipeline cost. A simple relationship is presented to estimate the total friction head loss of the proposed layout. Another simple relationship is presented to estimate the capital pipeline cost of the proposed layout. Both relationships are function of the side length of a square cultivated area, pump discharge, and several coefficients derived from basic equations of continuity and head loss.

Keywords: Sprinkler irrigation, system layout, total friction head loss, capital cost of pipeline.

1- INTRODUCTION

Although the economic design of hydraulic networks has received considerable emphasis since the 1960^s due to the emergence of high-speed computers (Goulter [2]; Perez et al. [3]), much research has been carried out on pipe networks using different optimization techniques, as were outlined by Dandy et el. [4]. David Karmeli and Gideon Oron [5] pointed out that an irrigation system has a large number of possible layouts where the different pipe sections, mains, submains, manifolds, and laterals have different lengths and diameters. The cost of the system is dependent upon the ratios among these different sections. A field of the same size may have different configurations and pipe section distributions.

Mostafa [7] presented nine alternative layouts for drip irrigation. Square cultivated area up to 150 Feddan was considered. Short and long laterals were considered for the same layout. Comparison was done to show the effect of increasing lateral length. Two different rotations were considered for the same layout and a comparison was done to show the effect of rotation on both pipeline cost and total friction losses. The author also presented a simple relationship which can be used to assess the total cost of pipe line of a certain layout. Moreover, a similar simple relationship was presented to assess the total head loss through the proposed layout. The relationships were based on several assumptions. The relationships were based on principles of pipe diameter choice, friction losses estimation, and pipeline cost criteria.

Herein, the author presents similar nine alternative layouts for sprinkler irrigation system to get the same goals.

2- ESTIMATION OF PIPE DIAMETER

The internal area of pipe, A, is given by:

$$A = Q / V = \pi * D^2/4 \quad (1)$$

where Q is the passing discharge, V is the mean velocity, D is the inner diameter of pipe.

Rearranging equation (1) and assuming V equals to be 1.0 m/s, the relation becomes:

$$D = C_1 (Q)^{0.5} \quad (2)$$

where C_1 is given in Table (1).

3- ESTIMATION OF FRICTION HEAD LOSS

3-1 Hazen-Williams Equation

Hazen-Williams equation is widely used in the estimation of friction head loss through different kind of pipes. It can be written as:

$$h_f = 10.77 * L * (Q/C_{HW})^{1.852} * (D)^{-4.865} \quad (3)$$

where,

h_f = friction head loss in meter
L = length of pipeline in meter
Q = discharge in m^3/sec
C_{HW} = Hazen-Williams Coefficient, for PVC pipes, C_{HW} = 140

D = internal diameter of pipe in meter

Alternatively, Mostafa [7] presented Hazen-Williams equation in the following form:

$$h_f = C_2 (C_1)^{C4} (Q)^{C3+0.5C4} L \quad (4)$$

He also simplified equation (4) to the following form:

$$h_f = C_5 * (Q)^{C6} L \quad (5)$$

where values of coefficients C_1, C_2, C_3, C_4, C_5, C_6 are given in Table (1).

Table (1) Values of coefficients, C_1, C_2, C_3, C_4, C_5, C_6.

Coefficient	**$C_1 = (4/\pi)^{0.5}$**	**C_2**	**C_3**	**C_4**	**$C_5 = C_2 (C_1)^{c4}$**	**$C_6 = C_3+0.5C_4$**
Value	1.128	$10.77(140)^{-1.852}$ = 0.00114	1.852	- 4.865	0.000634	-0.58

4- FRICTION HEAD LOSS

For lateral and manifold of constant diameter and varying velocity, a correction factor, F_1, is used as follows.

$$h_f = C_5 * (Q)^{C6} L F_1 \quad (6)$$

However, for lateral and manifold of varying diameter and constant velocity, 1.0 m/s, Mostafa [6] proposed a new correction factor, F_2.

$$h_f = C_5 * (Q)^{C6} L F_2 \quad (7)$$

Equations proposed by Mostafa [6], for the estimation of F_1 and F_2 are as follows

$$F_1 = [(n)^{C3} + (n-1)^{C3} + (n-2)^{C3} + \cdots (n-(n-1))^{C3}] / [(n)^{C3+1}] \quad (8)$$

$$F_2 = [(n)^{C6} + (n-1)^{C6} + (n-2)^{C6} + \cdots (n-(n-1))^{C6}] / [(n)^{C6+1}] \quad (9)$$

Where, [n-(n-1)] => 1, n is the number of outlets, C_3 and C_6 are given in Table (1).

Mostafa [7] uses the first correction factor, F_1 in drip irrigation design when the friction head loss is estimated through laterals and manifolds. In this paper, sprinkler system, F_2 can practically be used where the discharge is relatively large and spacing of outlets through laterals and manifolds are relatively long. Values of F_1 and F_2 are given in Tables 2 and 3, respectively. If minor losses are assumed to be 15% of friction head loss, the total head loss, H_L, may be written as:

$$H_L = 1.15\ C_5*(Q)^{C6}\ L\ F_1 \qquad (10)$$

$$H_L = 1.15\ C_5*(Q)^{C6}\ L\ F_2 \qquad (11)$$

When F_2 is used, Mostafa [6] proposed a relative cost ratio, RCR, defined as follows:

RCR = cost of varying pipe size / cost of constant pipe size
Average value of RCR = 0.6 was proposed by the author for about 6 outlets on the pipe, for example, 6 sprinklers constructed on lateral pipe.

Table (2) Values of correction factor, F_1, versus outlet numbers, Mostafa [6]

Correction Factor, F_1	**Number of outlets on lateral or manifold**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
using Hazen-Williams	1	0.639	0.534	0.485	0.457	0.438	0.425	0.416	0.408	0.402
using Darcy-Weisbach	1	0.625	0.519	0.469	0.440	0.421	0.408	0.398	0.391	0.385

Table (3) Values of correction factor, F_2, versus outlet numbers, Mostafa [6]

Correction Factor, F_2	**Number of outlets on lateral or manifold**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
using Hazen-Williams	1	1.247	1.385	1.478	1.546	1.598	1.641	1.676	1.707	1.733
using Darcy-Weisbach	1	1.207	1.319	1.392	1.445	1.486	1.519	1.546	1.568	1.588

5- TOTAL PIPELINE COST

Mostafa [6] proposed the following form:

$$\text{Pipe Cost} = C_9\ [D]^{C8}\ L \qquad (12)$$

where C_8, C_9 are constants vary according to market and can be estimated by regression analysis to the available pipe diameters. If V is assumed to be 1.0 m/s, the author rearranged the above equation to the following form:

$$\text{Pipe Cost} = (C_1^{C8})*C_9\ (Q)^{0.5C8}\ L = C_{10}*C_9\ (Q)^{0.5C8}\ L \qquad (13)$$

where

$$C_{10} = C_1^{C8} \qquad (14)$$

5-1 Regression Analysis to Available Pipeline Diameters

Regression analysis to available UPVC pipes leads to average value of C_8 and C_9 then the value of C_{10} is calculated. Mostafa [7] presented regression analysis to available pipeline diameters according to Egyptian market at that time and gave C_8 = 2.0 and C_9 = 1200.

5-2 Relative Pipeline Cost Versus Relative Discharge and velocity

For constant V and according to C_8 = 2.0, proposed by Mostafa [7], the relative cost may be given by:

$$Cost_1/Cost_2 = Q_1/Q_2 \tag{15}$$

Also, Mostafa [7] proposed:

$$Cost_1/Cost_2 = (Q_1/Q_2)\,(V_2/V_1)^{0.5C8} \tag{16}$$

For constant discharge and according to C_8 = 2.0, proposed by the author, the above equation may be given in the following form:

$$Cost_1/Cost_2 = 1/(V_1/V_2) \tag{17}$$

6- ESTIMATION OF DISCHARGE AND HEAD OF PUMP

The pump discharge, Q_p, is simply given by:

$$Q_p = \text{average water duty } (m^3/\text{fed/day}) * \text{cultivated area (fed)}$$

However, accurately, Q_p is given by:

$$Q_p = [2\; q_s\; n_s\; m_s\; K_s] \tag{18}$$

where q_s is the discharge of sprinkler, n_s is the number of sprinklers on lateral, m_s is the number of laterals on manifold, K_s is the number of working manifolds. For reason of comparison, Q_p, must be the same for all layouts, so Equation (18) is applied irrespective of the number of rotation.

7- ALTERNATIVE SYSTEM LAYOUT

Mostafa [7] proposed nine alternative system layouts for drip irrigation. Herein, the same nine layouts, Figures 1, 2, 3, 4, ….., 9, are also presented for sprinkler irrigation system. For all layouts same pump discharge, Q_p, is defined as the discharge required for the whole area in one rotation. For each layout, different pipeline diameter is estimated. To estimate the friction head loss in each layout, the path line a b c d e f is considered, as shown in Fig. 1, starting from end point to first. For each layout, total pipe line cost is estimated.

8- MAIN ASSUMPTIONS

For comparative analysis, the following assumptions are considered:

1- The velocity through all pipes equals 1.0 m/s.
2- Friction losses are only estimated and minor loss may be assumed to be 15% of that loss.
3- Value of F_1 for laterals and submains is assumed to be $F_1 = 0.44$ in the presented example.
4- Value of F_2 for laterals and submains is assumed to be $F_2 = 1.5$ in the presented example.
5- Hazen-Williams coefficient factor equals 140.

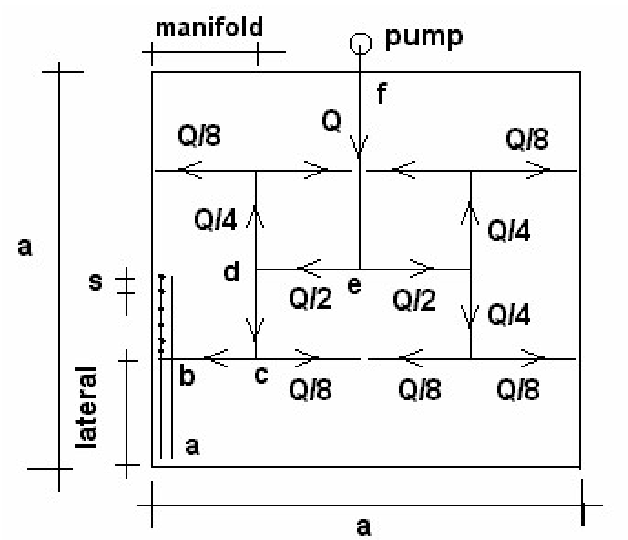

Fig. 1 Layout (1) of long laterals, rotation = 1

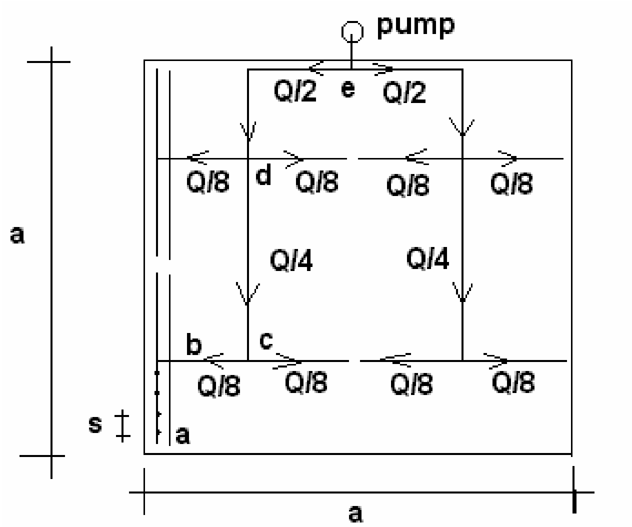

Fig. 2 Layout (2) of long laterals, rotation = 1

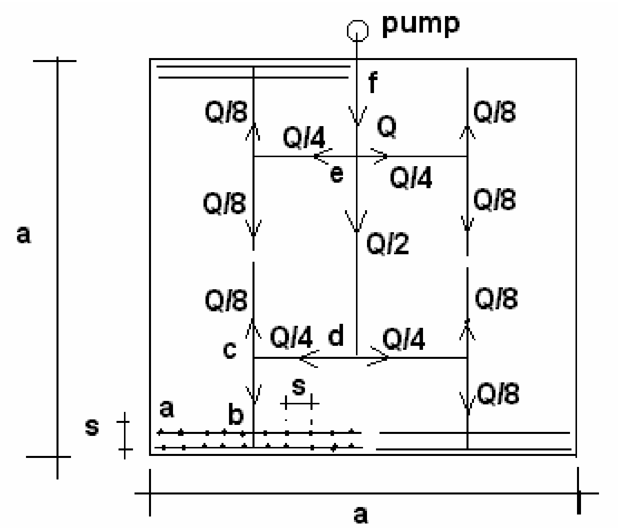

Fig. 3 Layout (3) of long laterals, rotation = 1

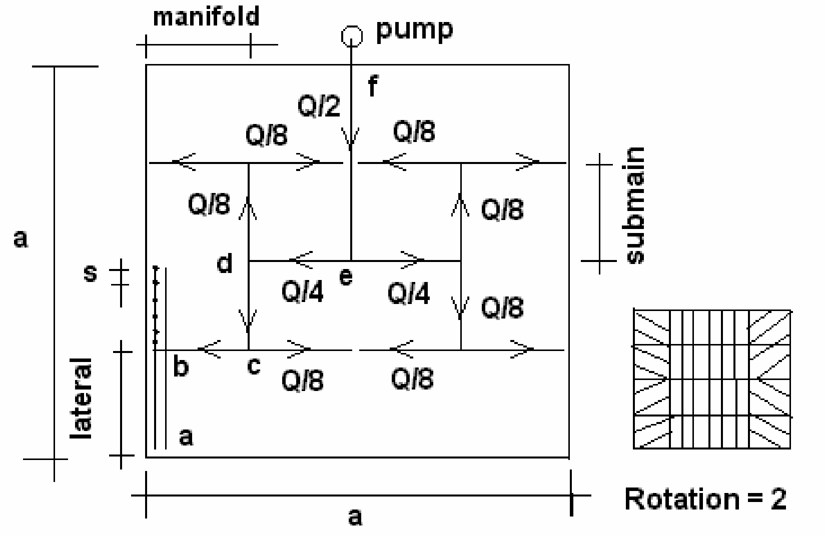

Fig. 4 Layout (4) of long laterals, rotation = 2

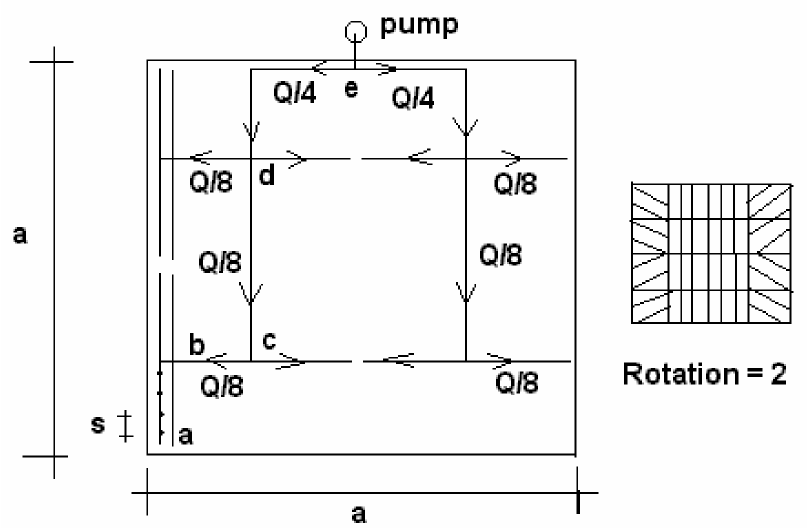

Fig. 5 Layout (5) of long laterals, rotation = 2

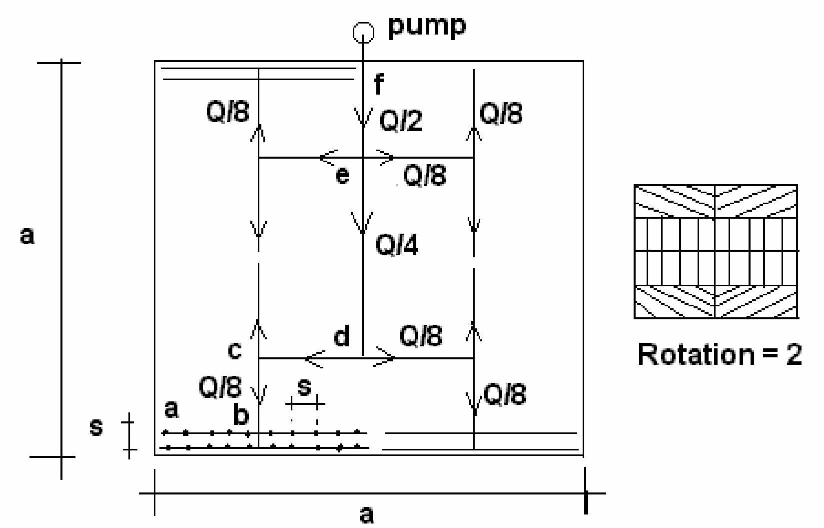

Fig. 6 Layout (6) of long laterals, rotation = 2

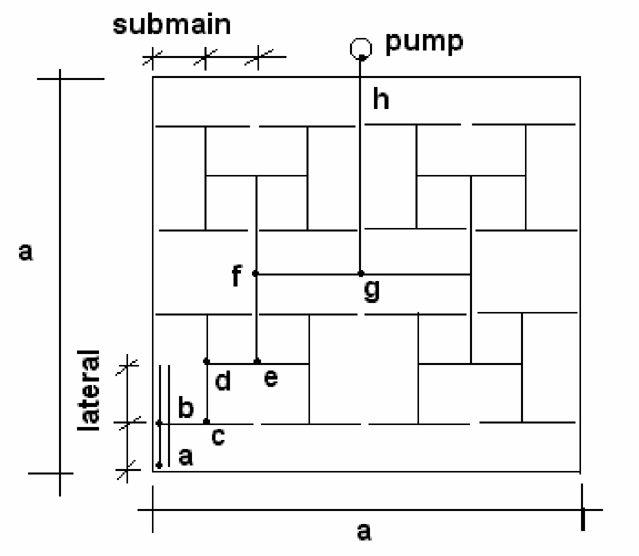

Fig. 7 Layout (7) of short laterals, rotation = 1

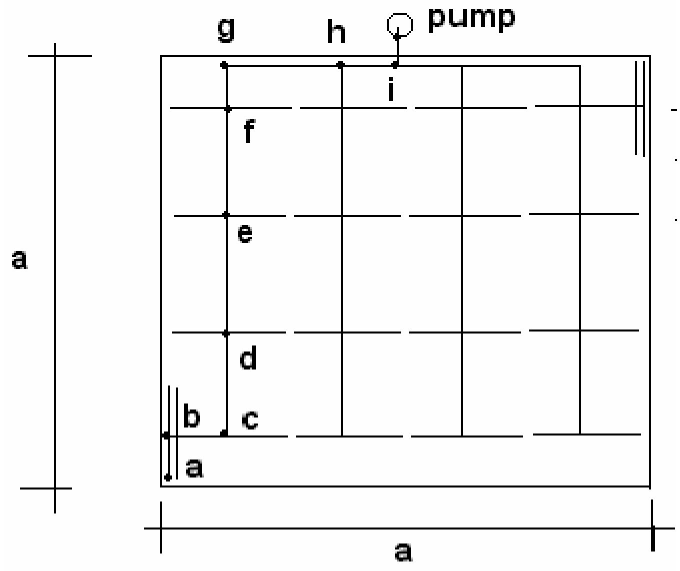

Fig. 8 Layout (8) of short laterals, rotation = 1

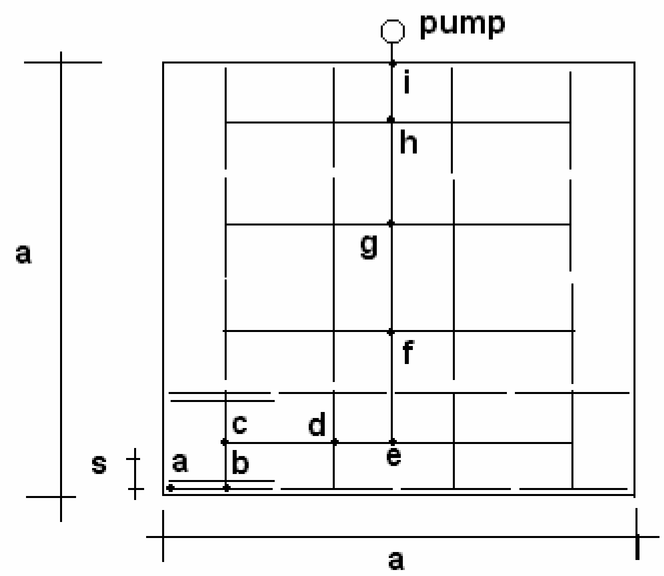

Fig. 9 Layout (9) of short laterals, rotation = 1

9- RESULTS AND ANALYSIS

9-1 Total Pipeline Cost Equations

Results of pipe line cost analysis are given in Table (4).

9-2 Total Head Loss Equations

Results of friction head loss analysis are given in Table (5).
Key for Tables (4) and (5):

Case (1) means constant pipe size, for example, ab Fig. 1, is of constant pipe diameter
Case (2) varying pipe size, for example, ab in Fig. 1, is of varying pipe diameters
LMC = Laterals and Manifolds Cost
TPLC = Total Pipe Line Cost or total capital cost of pipeline
FHL = Friction Head Loss through laterals and manifolds
TFHL = Total Friction Head Loss through all pipes

10- ANALYSIS

10-1 Effect of Layout Type

Tables (4) and (5) show proposed equations can be used to estimate the cost of pipelines and the friction head loss**,** respectively. Layouts (5) and (6) are the least cost of pipelines. Layout (1) has the least friction head loss. However, comparison of different layouts shows that:

1- The cost of pipelines of layout (1) is more expensive than that of layouts (2) & (3)
2- The total pipeline cost of layout (2) & (3) are the same
3- The total pipeline cost of layout (4) is more expensive than layout (5) & (6)
4- The total pipeline cost of layout (5) & (6) are the same
5- The total pipeline cost of layout (7) is more expensive than layout (8) & (9)
6- The total pipeline cost of layout (8) & (9) are the same

10-2 Cost of Laterals and Manifolds, LMC

It is shown that:

1- LMC/TPLC = 17% is minimum in layout 7 of short laterals. This means that the cost of laterals and manifolds represents 17% of the total cost of pipelines.
2- LMC/TPLC = 57% is maximum in layout 5, 6. This means that the cost of laterals and manifolds represents 57% of the total cost of pipelines.
3- Laterals and manifolds of varying diameters if possible lead to a reduction in the total pipeline cost. The reduction value ranges from 15% to 20%.
4- Laterals and manifolds of varying diameters if possible lead to an increase in the total pipeline head loss. The value ranges from 2 to 3 times.

10-3 Effect of Rotation

Two rotation leads to a reduction in the total pipeline cost, however, it leads to an increase in losses. This trend is valid when:

a- Layout 1 is compared with layout 4. A reduction in cost is about 40%. An increase in losses is about 20%.
b- Layout 2 is compared with layout 5. A reduction in cost is about 35%. An increase in losses is about 25%.

c- Layout 3 is compared with layout 6. A reduction in cost is about 35%. An increase in losses is about 20%.

10-3 Effect of Increasing Lateral Length

The comparison between layout 1 and layout 7 & layout 2 and layout 8 & layout 3 and layout 9 shows the effect of lateral length. In layout 1, lateral length equals a/4 while in layout 7, lateral length equals a/8. For case (1), the total pipeline cost of long laterals layout is about 25% more expensive than that layout of short laterals. However, the total head loss of long laterals layout is about 35% less than that layout of short laterals. For case (2), the values were 17% for pipeline cost and about 25% for losses.

Table (4) Pipe line cost analysis for different layouts

Layouts	Q_p	Case (1) means constant diameters		Case (2) means varying diameters	
		LMC	TPLC	LMC	TPLC
Layout 1	$2\ q_s\ n_s\ m_s\ K_s$ $= 16\ n_s\ m_s\ q_s$ Where $K_s = 8$	$0.5\ C_{10}\ C_9\ a\ Q_p$	$1.50\ C_{10}\ C_9\ a\ Q_p$	$0.3\ C_{10}\ C_9\ a\ Q_p$	$1.30\ C_{10}\ C_9\ a\ Q_p$
Layout 2			$1.25\ C_{10}\ C_9\ a\ Q_p$		$1.05\ C_{10}\ C_9\ a\ Q_p$
Layout 3					
Layout 4			$1.00\ C_{10}\ C_9\ a\ Q_p$		$0.80\ C_{10}\ C_9\ a\ Q_p$
Layout 5			$0.875\ C_{10}\ C_9\ a\ Q_p$		$0.675\ C_{10}\ C_9\ a\ Q_p$
Layout 6					
Layout 7	$2\ q_s\ n_s\ m_s\ K_s$ $= 64\ n_s\ m_s\ q_s$ Where $K_s = 32$	$0.25\ C_{10}\ C_9\ a\ Q_p$	$1.50\ C_{10}\ C_9\ a\ Q_p$	$0.15\ C_{10}\ C_9\ a\ Q_p$	$1.40\ C_{10}\ C_9\ a\ Q_p$
Layout 8			$1.00\ C_{10}\ C_9\ a\ Q_p$		$0.90C_{10}\ C_9\ a\ Q_p$
Layout 9					

Table (5) Friction head loss analysis for different layouts

Layouts	Case (1) means constant diameters		Case(2) means varying diameters	
	FHL	TFHL	FHL	TFHL
	$= aC_5\ Qp^{C6}$ multiplied by	$= aC_5\ Qp^{C6}$ multiplied by	$= aC_5\ Qp^{C6}$ multiplied by	$= aC_5\ Qp^{C6}$ multiplied by
Layout 1	$F_1\ [0.83+1.25m^{-C6}]$	$F_1\ [0.83+1.25m^{-C6}] +1.43$	$F_2\ [0.83+1.25m^{-C6}]$	$F_2\ [0.83+1.25m^{-C6}] +1.43$
Layout 2		$F_1\ [0.83+1.25m^{-C6}] +1.83$		$F_2\ [0.83+1.25m^{-C6}] +1.83$
Layout 3		$F_1\ [0.83+1.25m^{-C6}] +1.58$		$F_2\ [0.83+1.25m^{-C6}] +1.58$
Layout 4		$F_1\ [0.83+1.25m^{-C6}] +2.08$		$F_2\ [0.83+1.25m^{-C6}] +2.08$
Layout 5		$F_1\ [0.83+1.25m^{-C6}] +2.83$		$F_2\ [0.83+1.25m^{-C6}] +2.83$
Layout 6		$F_1\ [0.83+1.25m^{-C6}] +2.33$		$F_2\ [0.83+1.25m^{-C6}] +2.33$
Layout 7	$F_1\ [0.93+1.39m^{-C6}]$	$F_1\ [0.93+1.39m^{-C6}] +2.44$	$F_2\ [0.93+1.39m^{-C6}]$	$F_2\ [0.93+1.39m^{-C6}] +2.44$
Layout 8		$F_1\ [0.93+1.39m^{-C6}] +3.77$		$F_2\ [0.93+1.39m^{-C6}] +3.77$
Layout 9		$F_1\ [0.93+1.39m^{-C6}] +3.04$		$F_2\ [0.93+1.39m^{-C6}] +3.04$

Table (6) Data for example of area = 100 fed and analysis for different layouts

Data of example			Layouts	Q_p, m^3/s	Case (1)		Case (2)	
Area =	**100**	**Fed**			**LMC, L.E.**	**TPLC, L.E.**	**LMC, L.E.**	**TPLC, L.E.**
a =	650	m	Layout 1	0.68	337334.4	1012003.2	202400.64	877069.44
qs =	1.53	m^3/hr	Layout 2			843336		708402.24
qs =	0.000425	m^3/s	Layout 3					
lateral length =	162.5	m	Layout 4			674668.8		539735.04
manifold length =	162.5	m	Layout 5			590335.2		455401.40
sprinkler spacing =	15	m	Layout 6					
lateral spacing =	15	m	Layout 7	0.68	168667.2	1012003.2	101200.32	944536.32
ns =	10	F1 = 0.44	Layout 8			674668.8		607201.92
ms =	10	F2 = 1.5	Layout 9					
Ks =	8							
Qp =	0.68	m^3/s						

Table (7) Friction head loss analysis for different layouts, area = 100 fed

Layouts	Case (1) means constant diameters		Case(2) means varying diameters	
	FHL, m	**TFHL, m**	**FHL, m**	**TFHL, m**
Layout 1	1.266	2.0	4.32	5.05
Layout 2		2.2		5.26
Layout 3		2.1		5.13
Layout 4		2.34		5.39
Layout 5		2.73		5.77
Layout 6		2.47		5.5
Layout 7	1.4	2.66	4.8	6.0
Layout 8		3.34		6.75
Layout 9		2.97		6.37

11- CONCLUSION

The paper presents nine layouts for a sprinkler irrigation system. The designer is allowed to choose a sprinkler system layout for the cultivated area up to 150 Feddan and to apply preliminary equations to estimate both the total capital cost of pipeline and the friction head loss for the proposed system, provided that the velocity through pipes is assumed to be almost 1.0 m/s which is easy to be obtained through all pipes in sprinkler irrigation system.

According to data of price list available in Egyptian market proposed by Mostafa [7], the study shows that layout 1 has the least friction head loss. However, if rotation is applied, the layout 5 or 6 has the least total capital cost of pipeline. On the other hand; if no rotation is applied; layout 8 or 9 has the least total pipeline cost.

It is shown that the cost of laterals and manifolds in layout 7 represents 17% of the total cost of pipelines, while in layouts 5 and 6 they represents about 57% of the total cost of pipelines. Two cases are presented for the design of manifolds and laterals. Case (1) in which the diameter is set constant through all the length while in case (2) the diameter is varying between two different outlets. Case (2) leads to a reduction in the total pipeline cost. The reduction value ranges from 15% to 20%. Also, if possible it leads to an increase in the total pipeline head loss. The value ranges from 2 to 3 times.

When a two turn rotation is applied, the total pipeline cost decreases about 35% to 40%. However, the total head loss increased about 20 to 35%.

The total pipeline cost of long laterals layout is 20% more expensive than that layout of short laterals. However, the total head loss of long laterals layout is 35% less than that layout of short laterals.

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