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Fairness Water Distribution at On-Farm Irrigation Development Projects In Egypt - Case of Laser Levelling

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***Abstract*—** Improved irrigation projects in Egypt concern with converting mesqa and marwa in on-farm level from earth cross section to pipeline system. There are many advantages from these projects especially increase in the water use efficiency along the distribution system. Through the improved irrigation projects there is still a problem of unequal water distribution between hydrants due to random operating cases. The main objective of this paper is to detect the required operational conditions to achieve fairness water distribution between beneficiaries in case of constant land level due to laser leveling. Allowable limits for the concept of fairness water distribution are established with allowable difference in the discharge between opened hydrants with four limits $5\%, 10\%, 15\%, and\ 20\%$. Through this paper, the proposed distance between opened hydrants is detected to achieve the various limits of the discharge differences. Finally, this paper provides standard graphs and tables which can be used to control the operating cases between opened hydrants in improved irrigation projects in Egypt. These graphs and tables are studied for the case of laser leveling to achieve fairness water distribution between beneficiaries.

***Index Terms*—** Improved Irrigation System; laser leveling, On-farm Irrigation; Water distribution

I. INTRODUCTION

Egypt is one of the countries facing great challenges due to its limited water resources. Water resources in Egypt are represented mainly by its fixed share of the Nile water and its aridity as a general characteristic. Irrigation for agriculture consumes about 80% of water resources in Egypt [1]. In the near future, Egypt will face water scarcity due to the increased gap between water demand and water supply [1]. So, there is a need to manage water resources in Egypt to face the challenges in the future. Improved irrigation system at on-farm is an example of water management at the farm level. On-farm system consists of mesqas and marwas which are private properties owned, operated and maintained by the users (farmers) as shown in Fig. 1. Improved Irrigation Project (IIP) started at 1989 to improve about $400{,}000$ feddan at on- farm level [2]. IIP concerns with replacing the traditional cross section of mesqa as shown in Fig. 2 into another alternative cross section of low pressure pipeline system as shown in Fig. 3. Egypt continued in the improved projects by improving about $150{,}000$ feddan in the Nile Delta in Beheria governorate, and Kafr El sheikh governorate[3].

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The main advantages of IIP can be summarized by five main benefits. The first benefit is land saving of about 2 to 3% of the total command area due to construction of improved Mesqa as compared to areas occupied by old Mesqas [4]. The second benefit is the increase in crop yield ranging from $5\%\ to\ 30\%$ according to crop type due to the better condition of water availability [5], [6]. The third benefit is the decrease in the irrigation time due to implementing land levelling and setting

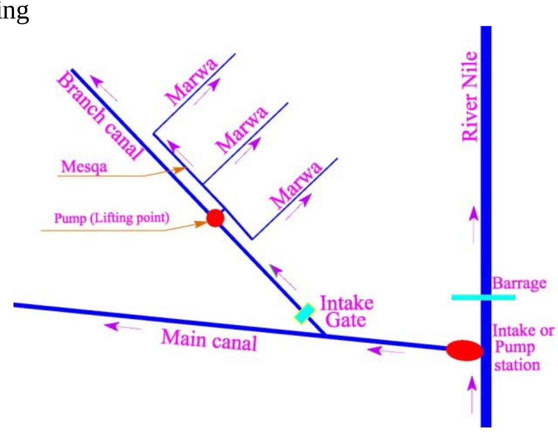


Fig. 1. Schematic Irrigation System in Egypt.

Fig. 2. Traditional Mesqa Shape before Improvement.

Fig. 3. Improved Pipeline Mesqa

a suitable water head at the farm inlet. Time of irrigation was also reduced because of the continuous flow, which made water available all the time in the Mesqa [7], [8] . The fourth benefit is the increase in the expected farm income as a result of the project improvements. Improved mesqas allows reductions in the farms' pumping cost of irrigation estimated in about $35\ to\ 42$ percent in financial terms and reduction in labour requirements [8], [9]. The last benefit is the increase in the quality of the irrigated water which help in avoiding water-borne diseases, due to that the opened mesqa includes high pollution [10].

The main components of Improved Irrigation Project in On- Farm System consists of three main components as shown in Fig. 4. First component is improved mesqa or branch mesqa with low pressure pipeline (IIP project). The second component is improved marwa with low pressure pipeline (if exist). The last component is the pump station as shown in Fig. 5. Butterfly valve was used in improved irrigation projects (IIP) at the head of unimproved marwa (earth marwa).

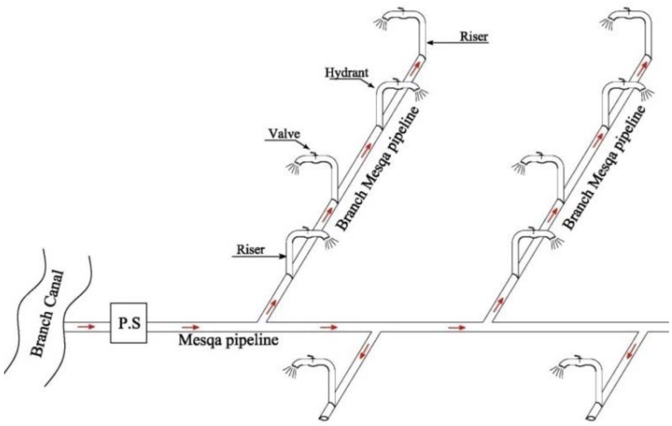


Fig. 4. Main Components of Improved Irrigation Project (IIP).

Fig.5. Pump House and Sump Pump for IIP [11].

The design of improved irrigation system consists of detecting the suitable diameters for low pressure pipeline network for mesqa and marwa. In addition to detecting the required pump specifications to ensure extracting the designed water discharge from the far hydrant on the last marwa pipeline. Design of improved irrigation system have passed through several stages; starting from using Mesqa and Marwa Hydraulic Design program "MMHD" which is an open program source. Improved irrigation sector in Egypt uses this computer program with its limited capabilities for mesqa design [12]. After that, the design procedures used in MMHD program have been improved by developing a new program using Matlab software. The new program came to avoid some existing problems in MMHD program and to study the effect of different design modifications [13], [14]. There was concern about the high cost of the IIP improvements (civil works and associated equipment). The total cost has increased from about $2{,}300\ LE/fed$ at the time of mid-term review in May 2000 to about $5{,}600\ LE/fed$ in 2004 [15]. To repay the costs of improvements, farmers would have to make annual payments per $feddan$ per year over several years ranges from $10\ to\ 20$ year. So any reduction in the total improved system can relief something from the farmer's problem [1]. The new developed program has helped in discussing the available methods to reduce the total improvement's costs [13],[14], and[16].

For unimproved system and at the tail-end of the mesqa, the farmer suffers from water shortage. So, the farmer completes his required water from the nearest agriculture drains with low water quality. The farmer at on-farm needs to ensure from the availability of sufficient water supply at the required irrigation time with fair distribution between other farmers. Due to random operational opening between farmers, water distribution between beneficiaries is not fair. So, there is a need to study how to achieve justice in water distribution between users for improved on-farm irrigation system at old lands in Egypt.

However, most of the researchers have stated the existence of justice in water distribution between farmers without verifying the authenticity of this speech. But, through this paper we will emphasis on the conditions to be met to achieve the fairness of the distribution of water between users.

II. DESDIGN CONCEPT FOR IMPROVED ON-FARM IRRIGATION SYSTEM

The design criteria passes different steps as follows:

A. *Detection of Mesqa Capacity.*

Calculation of mesqa capacity is allowed for 100% rice cropping in the served area with peak daily consumptive use for rice of $13.3\ mm$. Assuming percolation losses of $1.0\ mm/day$. Then increase the previous total water requirement by 10% for surface runoff, and that led to a designed peak water duty(W_D) requirement equals $15.7\ mm/day$. Then mesqa capacity ($l/sec.$) can be calculated as in (1).

$$Q = \frac{4200 \times A \times W_D}{T}, \quad (1)$$

Where Q, A, W_D, T are mesqa capacity ($l/sec.$), Total served area ($feddan$), Water duty requirement (mm/d), and Working time per day ($seconds$) respectively. The designed discharge for a single hydrant is either $20\ l/sec.$ or in some times is $30\ l/sec.$ The total number of working hydrants at the same time can be detected by dividing the calculated mesqa capacity by the selected design hydrant discharge. In this paper, it is assumed that there are two working hydrants at the same time.

B. *Calculation of the suitable pipe diameters.*

Selection of the suitable pipeline diameter depends on the available commercial pipe diameters, and maximum design velocity. The available commercial pipe diameters are ($200, 250, 315, 355, 400, and\ 450\ mm$) with pressure head of 4.0 $bars$. The maximum design velocity was changed from 1.0 m/s for old design criteria to 1.5 m/s for new design criteria as a step for total cost reduction.

C. Detecting the Suitable Pump

One of the main important components of the improved irrigation system is the pump. The suitable pump is selected to overcome the final required pressure head and discharge for the critical operating case. Detecting the required pressure head is calculated to overcome total head losses through the critical operating case. Head losses are divided into losses at outlets (hydrants) and losses through reaches. Hydraulic gradient at outlets is calculated from the following equation (for more details see [14]):

$$H_{GL} = L_L + H_{Riser} + O_P + CQ^2 \qquad (2)$$

Where $H_{GL}, L_L, H_{Riser}, O_P, Q$ are hydraulic gradient at hydrant (m), land level at hydrant, height of the riser above land level, required outlet pressure at hydrant (m), actual extracting discharge ($m^3/sec.$) respectively. Parameter C is depending on friction coefficients, and it can be calculated from the following equation $C = K_T/(2g\ A_{Riser}^2)$. Where K_T is the summation of total friction coefficients at hydrant location taken 4. Parameters g , and A_{Riser} are the gravity acceleration (9.8 m/sec^2), and cross section area of the riser pipe (m^2) respectively.

Head losses through reaches are divided into minor and main losses. For more details about minor losses see [17],[18]. Main friction losses through improved mesqa or marwa pipelines (h_f) are calculated using Hazen-William equation:

$$h_f = \left(\frac{3.59\,Q}{CH}\right)^{1.852} \left(\frac{L}{D^{4.87}}\right) \qquad (3)$$

Where H_f, CH, D, L are friction losses in pipeline (m), coefficient taken 150 for P.V.C pipe, diameter of pipeline reach (m) , and Length of pipeline reach (m) respectively.

III. Conditions For Fairness Water Distribution

In this section, the operational conditions for equity water distribution between opened hydrants will be discussed. The relationship of the hydraulic gradient line (H_{GL}) between two opened hydrants (i, and j) is governed by the following equations, see Fig. 8.

$$H_{GLi} = L_{Li} + H_{Riser\,i} + O_{Pi} + C{Q_i}^2 \qquad (4a)$$

$$H_{GLj} = L_{Lj} + H_{Riser\,j} + O_{Pj} + C{Q_j}^2 \qquad (4b)$$

$$H_{GLj} = H_{GLi} - h_{l\,ij} \qquad (4c)$$

Where $h_{l_{ij}}$ is the friction losses between hydrants (i , and j). Equation 4 can be rewritten to get the following relationship between the discharge of any two opened hydrants.

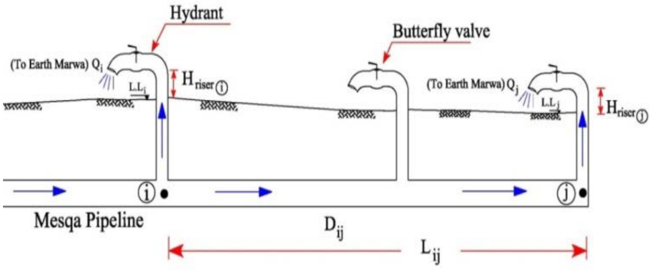


Fig.8. Illustrated Figure for Improved Mesqa Pipeline with Earth Marwa (Iip).

$$C\left(Q_i^2 - Q_j^2\right) = \left(O_{P_j} - O_{P_i}\right) + \left(L_{L_j} - L_{L_i}\right) + h_{l_{ij}} \qquad (5)$$

Where

$$h_{l_{ij}} = \left(\frac{3.59\,Q_j}{CH}\right)^{1.852} \left(\frac{L_{ij}}{D_{ij}^{4.87}}\right)$$

$$\therefore\ C\left(Q_i^2 - Q_j^2\right) = f\left(O_P, L_L, Q_j, L_{ij}, D_{ij}\right)$$

This paper deals with the scenario with constant land level (L_L) through laser leveling, and constant outlet pressure (O_P). So, for this scenario the following relationships will be valid for opened hydrants $i, and\ j$ ($L_{L_i} = L_{L_j}$, $O_{P_i} = O_{P_j}$). Using this assumption, (5) can be rewritten in the following form:

$$C\left(Q_i^2 - Q_j^2\right) = h_{l_{ij}} = \left(\frac{3.59\,Q_j}{CH}\right)^{1.852} \left(\frac{L_{ij}}{D_{ij}^{4.87}}\right) \qquad (6)$$

To apply 6 and get the corresponding results, the following steps should be followed:

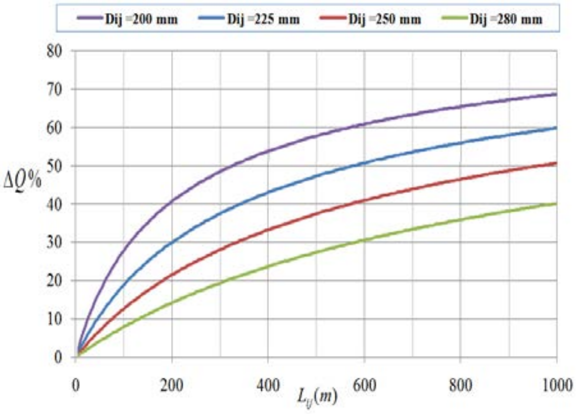
- Assume two constant values for Q_j (the designed flow for far hydrant) first with 20 l/sec, and the second value with 30 l/sec .
- For each value of Q_j, assume different values of the diameter between opened hydrants D_{ij}.
- For each value of D_{ij}, Several values for (L_{ij}) (distance between opened hydrants) should be assumed and the corresponding discharge for nearest opened hydrant Q_i is calculated using 6.
- Determine the percentage of difference in the discharge ΔQ between the opened hydrants Q_i, Q_j as follows:

$$\Delta Q = \frac{Q_i - Q_j}{Max.(Q_i, Q_j)} \times 100 \qquad (7)$$

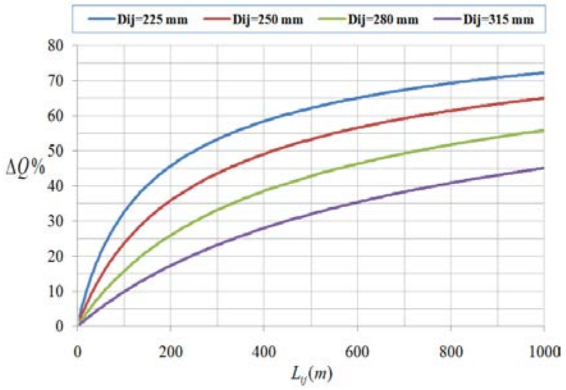
Accepted limits for ΔQ between opened hydrants are assumed with different values of 5%, 10%, 15, and 20%. The decision maker should choose the suitable limit representing the fairness water distribution between opened hydrants. For each accepted limit, the maximum distance between opened hydrants is detected for fairness water distribution. Fig.9 illustrates the relationship between ΔQ , and distance between opened hydrants for different values of D_{ij}. Table 1 illustrates the maximum accepted distance between opened hydrants for different accepted ratios of ΔQ between opened hydrants.

Table I can be used to control the operation between different marwas on the same mesqa. Table 1 can be used to select the marwas that should be opened at the same time depending on the required difference in the discharge. It is clear from this table that, as the allowable difference in the discharge increases, as the maximum accepted distance between opened marwas increases. Also it can be concluded that for the same discharge's difference, as the reach's diameter increases as the allowable accepted distance increases due to lower friction losses occurs in higher diameters. For the same discharge's difference and for the same diameter, as the design discharge increases from 20 to 30 l/s , as the allowable accepted distance decreases due to higher friction losses.

Table I concerns with the accepted distance between opened hydrants in case of constant reach's diameters D_{ij}between opened hydrants (see Fig. 8).



(a)



(b)

Fig.9. Relationship between Distance of Opened Hydrants and Discharge Difference (A) $Q_j = 20l/sec$ (B) $Q_j = 30\ l/sec$

But, in case that the reach's diameter between opened hydrants is different, the accepted distance between opened hydrants can be obtained using combinations from Table 1. For example, assume that the reach between opened hydrants i, j contains two different diameters as shown in Fig.10. The reach between opened hydrants starts with $200\ mm$ then $225\ mm$, and assume designed discharge of $20\ l/sec$. At this case there is an intermediate point will be appeared called " k" at the border line between the two different diameters.

Assume that it is required to know the accepted distance between opened hydrants i, j for a discharge difference of 10 % . So the discharge difference should be divided into two parts. If discharge difference is divided into two equal parts

TABLE I

MAXIMUM ACCEPTED DISTANCE BETWEEN SELECTED OPENED HYDRANTS (L_{ij}) IN METER FOR VARIOUS DIFFERENCE IN THE DISCHARGE.

		$Q_j = 20l/Sec$				$Q_j = 30l/Sec$			
$D_{ij}(mm)$		200	225	250	280	225	250	280	315
ΔQ %	5	11.7	20.8	34.7	60.2	9.1	15.1	26.2	46.55
	10	25.4	45.0	75.2	130.7	19.60	32.8	56.9	100.9
	15	41.66	73.8	123.2	213.9	32.12	53.6	93.07	165.1
	20	60.9	108.0	180.4	313.3	47.01	78.5	136.3	241.9

each of 5%, so standard curves in Fig.9 can be used as shown in Fig.11. From Fig.11, the corresponding maximum distance for each diameter can be detected or by using Table 1. From Table 1, the maximum distance for diameter $200\ mm$ will be $11.7m$ ($L_{1(Max.)}$) , and $20.8\ m$ for diameter $225mm$ ($L_{2(Max.)}$) so the total accepted distance between opened hydrants will be $32.5\ m$. For other splitting ratios of the discharge difference rather than 5% and not found in Table 1, standard graphs in Fig.9 should be used.

Assume there are obligatory opened hydrants with existing distance $L_{1_{Act}}, and\ L_{2_{Act}}$ for the two different diameters. It is required to know the actual difference in discharge. Under the assumption that the far outlet extracts the designed discharge $20\ or\ 30\ l/sec.$,the coming steps can be followed. First, enter the standard graph with the actual distance for each diameter $L_{1_{Act}}, and\ L_{2_{Act}}$ for diameter $200mm$ and $225\ mm$, respectively as shown in Fig. 11. Second, get the corresponding ΔQ_1 , ΔQ_2. Finally, the actual difference in the discharge between opened hydrants will be the summation of ΔQ_1 , ΔQ_2 as illustrated in the following equations.

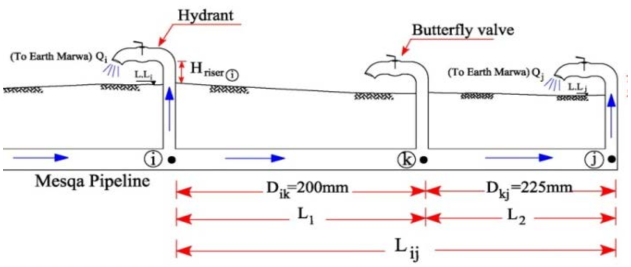


Fig.10. Case for Different Diameters between Opened Hydrants.

$$\Delta Q_1 = \frac{Q_i - Q_k}{Q_i} \times 100 \qquad (8a)$$

$$\Delta Q_2 = \frac{Q_{ki} - Q_j}{Q_k} \times 100 \qquad (8b)$$

$$\therefore \Delta Q = \frac{Q_i - Q_j}{Q_i} \times 100 = \Delta Q_1 + \Delta Q_2 \qquad (8c)$$

IV. CONCLUSIONS

This paper is dealed with establishing the required operational conditions for opened hydrants on the improved on-farm irrigation projects in Egypt. These operational conditions ensure fairness water distribution between beneficiaries along the same mesqa. Different accepted and allowable limits for the concept of fairness water distribution have beed established. The concept of fairness water distrobution was based on allowable difference in the discharge between opened hydarnts with four limits 5%, 10%, 15%, and 20%.

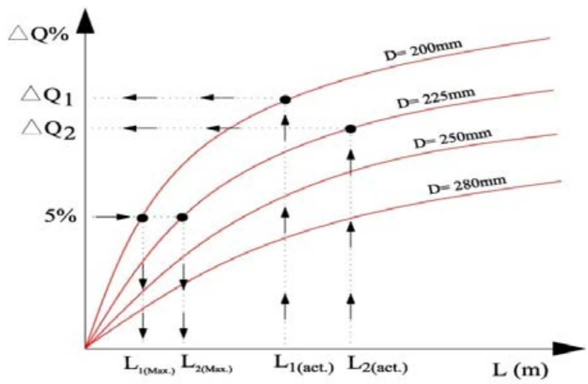


Fig.11. Case for Different Diameters between Opened Hydrants.

The final decision for choosing the suitable limit is left to the decision makers.The required conditions for achieving each limit of the above limits were developed.

The previous concept was applied for the case of constant land levels (through laser leveling) and constant outlet pressures for all hydrants. Standard graphs and tables were developed for this case. These graphs and tables can be used to detect the best proposed operational scenario for fairness water distribution. The proposed operational scenario is chosen depending on the accepted and allowable differences in the discharge between opened hydrants. Also these graphs can be used to detect the actual difference in the discharge between random opened hydrants.

Finally this paper discussed the required conditions to achieve fairness water distribution between beneficiaries for on-farm irrigation development projects in Egypt.

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