ISSN 2229-5518

Water Saving from Improved On-Farm Irrigation Projects in Egypt

Hany G. Radwan

Abstract— Egypt has reached a level where the quantity of water available is imposing constraints on its national economic development. Egypt has passed already the threshold for water scarcity problems (1000 m^3/capita/year) in nineties. Population explosion will bring Egypt down at 2025 to the threshold of absolute scarcity (500 m^3/ capita/year). One of the main strategies for the Ministry of Water Resources and Irrigation (MWRI) in Egypt to face this problem was to increase water use efficiency and decrease water losses. One of the selected projects by the ministry to achieve this goal was the improved on-farm irrigation projects by replacing the existing earth cross sections of mesqas and marwas at on- farm level by either lined sections, or elevated concrete sections, or buried pipelines sections. One of the main advantages of the improved on-farm system is water saving, improve the quality of the irrigation water in addition to other benefits. Through this paper the expected water saving from the evaporation and seepage losses are calculated in case of using each alternative for the improvement of mesqas/marwas (lined, elevated concrete, pipeline) compared to the existing earth cross sections. Sensitivity analysis of different design parameters on the calculated evaporation and seepage losses were discussed. Guideline equations that can be used to calculate the expected water losses due to evaporation and seepage from on-farm irrigation system in Egypt were developed. Finally the paper concluded that the expected minimum, maximum, and average annual water saving from improved on-farm irrigation projects in Egypt are about **2.6, 6.72, and 4.67 BCM,** respectively.

Index Terms— Evaporation losses, Improved irrigation projects, On-farm system, Seepage losses, Water saving

1 Introduction

Egypt is unique among the nations of the world due to its main dependence upon a single water source, the River Nile. Water demands in Egypt are growing rapidly due to the population explosion and the rising standard of living. The prepared national water balance for Egypt by year 2025 specified that there was an overall deficit in the near future of about 8 billion m^3 (BCM) assuming unchanged in the Egyptian Nile's water share due to the construction of Grand Renaissance Ethiopian Dam ($GERD$). This shortage takes into consideration increasing the use efficiency of available water resources through reuse of drainage water and use of groundwater. Ministry of Water Resources and Irrigation ($MWRI$) in Egypt face a lot of challenges such as deterioration of water quality, and growing demand-supply gap in addition to other problems [1]. The available fresh water per capita in Egypt dropped from 1893 cubic meters per person in 1959 to 800-900 cubic meters in 2000 and tends to decline further to the values of 670 cubic meter by 2017 and 600 by 2025 (see Figure 1) [2, 3]. According to statistics, if the available fresh water per person drops below 1700 cubic meters, countries are considered as water stress regions. When per capita water use falls below 1000 cubic meters, countries undergo a chronic water scarcity, and less than 600 cubic meters of water per person would mean absolute water scarcity [2]. So, Egypt by year 2025 will face absolute water scarcity. The consumed water for irrigated agriculture is about 85% of the budget of MWRI while 10% are dedicated to services for the water supply and sanitation sector, and 5 % attributed to the industrial sector [3].

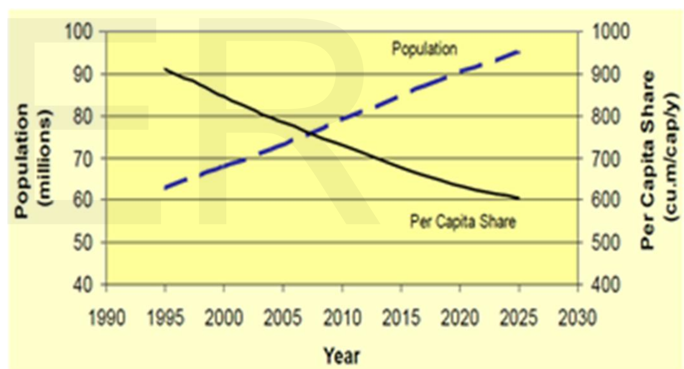

Figure 1: Projected Annual per Capita Share of Renewable Water Resources in Egypt [3]

The growing water demands for agriculture, industry and urban areas under expected water deficits have demanded an ongoing and dynamic national strategy and to reform policies to manage water more effectively. So, different policies for increasing the usable water supply or improving the efficiency of water use have been identified such as (1) Improved management of the irrigation system, (2) Reduced flows to the sea by storage in northern lakes, (3) Increased exploitation of groundwater, and (4) Expansion of drainage water reuse [1]. The irrigation system of canals in Egypt is quite complex as it comprises of more than 30,000 km of public canals, approximately 80,000 km of mesqas and farm ditches, 560 large public pump stations, over 17,000 km of public drains, 45,000 lifting devices (Saqias, small pumps,...etc.) and over 22,000 water control structures [4,5].

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ISSN 2229-5518

The irrigation system in Egypt can be divided with respect to size, responsibility, and operation and control into two categories:

1. Off-farm system or sometimes called main canal system which consists of all canals larger than the Mesqa.
2. On-farm system or sometimes called Farm Distribution System (FDS) which consists of Mesqas and smaller order ditches called marwas (see Figure 2). FDS usually serves areas ranging from 10 to 500 $feddans$

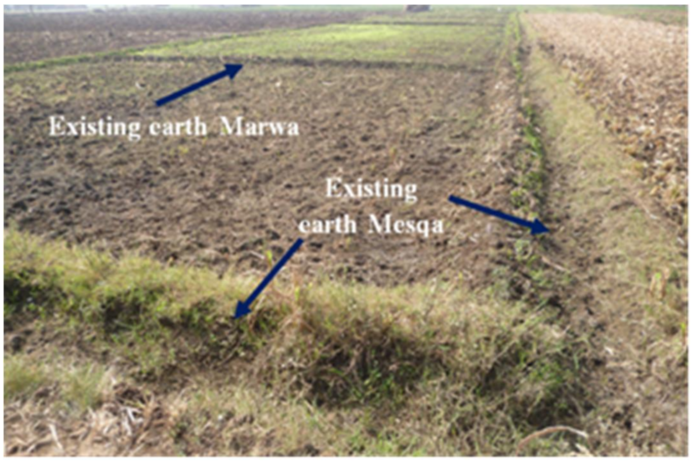

Figure 2: Main components of FDS.

The MWRI is the leading official government entity assigned for water management at the off-farm level starting from the Nile River down to the main- and secondary-canal levels. The tertiary-canal and on-farm levels are privately owned by farmers. However, $MWRI$ and The Ministry of Agriculture and Land Reclamation ($MALR$) are entrusted to help farmers improve water management at the mesqa and marwa levels respectively [4]. The overall efficiency of the irrigation system in Egypt is highly affected by the performance of the farm distribution system or simply the farm irrigation system. The farm distribution systems suffer from conveyance losses, distribution losses, and field application losses. The capability of these systems to deliver adequate timely irrigation water to all field areas is crucial to ensure good crop and eliminate any water stress [4]. It is popular to have more than one or two kilometres of FDS to serve more than sixty users. Mesqas and marwas in FDS are usually below grade earthen ditches which are frequently heavily infested with weeds that reduce its conveyance capacity in addition to the existing high seepage and evaporation losses in earth mesqa and marwas (see Figure 3).

So, a lot of improvements have been achieved at off-farm and on-farm systems in order to reduce the water losses in the irrigation network. At on-farm level, the existing earthen cross sections of mesqa and marwa are suggested to be improved with three possible design alternatives (see Figure 4). The main objectives are to overcome the flow distribution problems, avoid any wastage and provide greater direct control over water used by farmers. First improved alternative concerns with replacing the earthen cross sections of FDS with lined sections and the rehabilitation of all old structures and adding regulating and control structures (see Figure 4a). For this alternative, the water is controlled for best delivery using check structures, turnout gates and intake structures [6].

(a) (b)

Figure 3: (a) Earth mesqa in a deteriorating condition, (b) Earth mesqa infested with weeds

(a) (b)

(c)

Figure 4: (a) Improved raised concrete mesqa, (b) Improved lined mesqa, and (c) Improved low pressure pipeline mesqa

Second improved alternative concerns with replacing the earthen cross sections of FDS with raised reinforced concrete sections provided by turnouts with control gates or weirs and check structures. Several turnouts with steel gates can deliver water directly into the field distribution system (marwas) where water heads should be at least 20 cm above land level (see Figure 4b). On the other hand these several turnouts for the second alternative are considered weak points for seepage losses [6]. Third improved alternative concerns with replacing the earthen cross sections of FDS with buried low pressure pipelines (commonly from PVC) fed by a single pump station at the beginning of the line and provided by turnouts at the head of each farm (see Figure 4c). Normally, regulation of the flow is made at the delivery (farm) outlets where water is delivered at a head of at least 1.0 m above the land [6]. Low pressure pipeline is the most common used alternative between other alternatives (Improved lined mesqa, and raised concrete mesqa) [6]. According to the design of about 2,263 km of mesqas, estimations were such that 60% of the mesqas are improved to be pipelines, and 40% for lined sections [7]. That doesn't mean the lined mesqa isn't preferred by farmers, but it is used for little percentage between 5 to 10 %. Pipeline mesqas are recommended for areas from 20 to 50 ha and have a length of 250– 1000 m; outside this range raised mesqas are recommended from the economic point of view [6].

The improved on-farm irrigation system was started at 1989 with Improved Irrigation Projects (IIP) through replacing the earthen cross section of mesqa by low pressure pipeline to improve about 400,000 $feddan$ at on-farm level [8]. At 1996, Egypt started the cooperation with the World Bank to improve area of about 250,000 feddan in Beheira, and Kafr el Sheikh Governorate [9]. IIP resulted into several benefits, increase the conveyance efficiency in the Mesqa to about 98% instead of about 70% before IIP, reduce in the irrigation time due to continuous flow, which made water available all the time in the Mesqa, improve the quality of irrigated water, and increase in crop yield from 5% to 30% according to crop type [10-14]. The plan for Egyptian government is to continue the improvement works to reach a target of about 3.0 million feddan by year 2017 [15, 16]. Due to the highly positive impacts of IIP, Integrated Irrigation Improvement and Management Project ($IIIMP$) came to continue the success by studying the environmental contamination by diesel pumps used in IIP and converting them to electrical pumps, studying unsatisfactory operation of the irrigation system under continuous flow conditions due to no systematic planning of water scheduling [17, 18]. $IIIMP$ was financed by the World Bank, German Development Bank KfW, the Kingdom of the Netherlands and the Government of Egypt (GoE). This project is expected to improve the irrigation efficiency at on-farm level through replacing earthen cross section of marwas to one alternative of the improvement.

The conveyance losses from the existing on-farm irrigation system consist of the evaporation and seepage process which affect the overall efficiency at FDS. The existing efficiency of the agricultural system at FDS is about 60-70 %. Evaporation losses from the canals, estimated at about 2.0 billion m^3/year for the whole country [1]. The expected saving in irrigation water due to improvement of the irrigation systems on the branch and field canal level in an area of about 400,000 $acres$ in the old lands in Egypt is about 5-10% [1]. High efficiency levels of irrigation in Egypt are required to reduce irrigation water losses. For example Irrigation Improvement Plan (IIP) was expected to save one billion cubic by year 2000 [19].

The main objective of this paper is to investigate the potential water saving from improved on-farm irrigation system in Egypt.

2 Methodology

In order to achieve the main objective of this paper, the methodology illustrated in Figure 5 will be applied. The methodology started with the description of the main design concept of improved on-farm irrigation system. Then the main design parameters and properties for the existing earthen cross section as a reference, and two improved alternatives (lined and concrete section) at on-farm irrigation system will be studied. Due to that the expected water saving will be from the evaporation and infiltration losses, the main governing equations for these losses will be discussed corresponding to the existing and the two improved alternatives. Through each cross section (earthen, lined, and concrete section), a sensitivity analysis of each design parameter on the evaporation and seepage losses will be discussed. Then some statistical measures will be determined accompanied with developing approximate equations for the calculation of the evaporation and seepage losses for each cross section. And finally the expected total water saving from the whole improved on-farm irrigation projects in Egypt will be calculated.

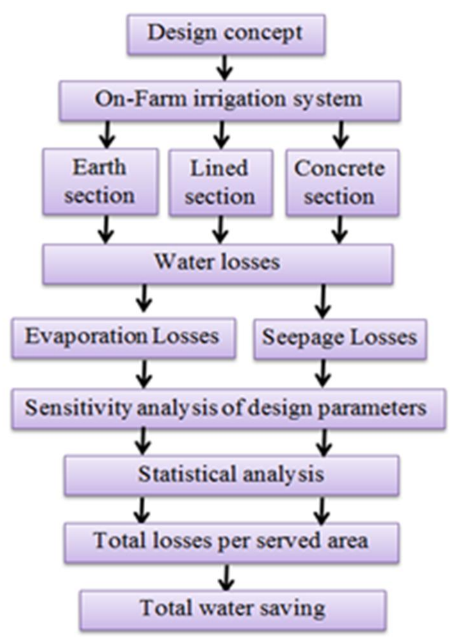

Figure 5: Methodology procedures for the calculations of potential water saving from improved on-farm irrigation system.

3 Design Concept

The design concept of improved irrigation system starts with detecting the mesqa and marwa's capacity (discharge) through applying in the following equation:

$$Q = \frac{4200 A_s W_D}{3600\, t\, \eta_1 \eta_2} \qquad (1)$$

where; $Q, A_S, t, and\ W_D$ are mesqa/marwa capacity ($l/sec.$), total served area ($feddan$), working time per day ($hours$) (default 16 $hour/day$), and water duty requirement (mm/d), respectively. Considering the served area is cultivated by Rice, the water duty will be about 15.7 mm/day. Also η_1, η_2 are the field application efficiency (0.9 for Rice), and conveyance efficiency (taken 0.85), respectively. Different values for the served area will be assumed starting from 20 to 160 $feddan$, and the corresponding design discharge for each cross section will be calculated.

By knowing the dimensions for each cross section (earthen, lined, and concrete section) such as bed width, longitudinal slope, and side slope, the expected water depth at the cross section can be calculated through applying Manning equation [20]:

$$Q = AV, \qquad (2a)$$

$$V = \frac{1}{n} R^{\frac{2}{3}} \sqrt{S}, \qquad (2b)$$

$$A = (b + zd)d, \qquad P = b + 2d\sqrt{1 + z^2}, \qquad R = \frac{A}{P} \qquad (2c)$$

Where $Q, V, n, and\ S$ are flow rate (m^3/s), flow velocity (m/s), Manning's coefficient, and channel's longitudinal slope (m/m), respectively. Flow area (A) in square meter can be calculated as in Equation 2c as a trapezoidal section in terms of bed width $b(m)$, and water depth $d(m)$, and side slope z ($H:V$). Hydraulic radius R (m) represents the ratio between the cross section area (A) to the cross section perimeter (P) as described in Equation 2c.

4 On-Farm Irrigation System

The main properties of the existing earthen cross section of mesqa and marwa (see Figure 3) in addition to two improved alternatives of lined and concrete section (see Figure 4a,b) can be illustrated in Table (1). The study focused on the first two improved alternatives for lined and concrete sections rather than low pressure pipeline system because natural losses due to evaporation and seepage are only occurred for these two alternatives.

5 Water Losses

Water losses at on-farm system can be divided into three types; first type is evaporation losses due to opened water sections, second type is seepage losses from the perimeter of opened water section, and last type is junctions' losses due to incompetent implementation method. Water losses for low pressure pipeline alternative come only from junctions losses. Through this paper, it is assumed that the construction method is good enough to eliminate or reduce the expected junctions' losses, and only water losses will emanate due to the first evaporation and seepage losses. So, this paper will focus on the calculations of the expected water saving due to reducing evaporation and seepage losses from improved alternatives lined/concrete section compared with the current earthen cross section.

Table 1: Main properties for existing and improved on-farm irrigation system in Egypt

Item	Existing Situation	Improved on-farm irrigation system	
	Earth cross section	Lined section	Concrete section
Served area per Mesqa (fed.)	30-100	30-100	30-160
Served area per Marwa (fed.)	10-20		
Longitudinal slope (cm/km)	20-40	20-40	20-60
Section side slope (H:V)	2:1 , 3:2	1:1 , 1.25:1	0:1
Manning coefficient (n) [21]	0.028-0.035	0.012-0.017	0.011-0.025

5.1 Evaporation Losses

Evaporation losses at on-farm irrigation system are extracted from the top water surface area of opened water section for meaqa and marwa. The evaporation losses at on-farm system will be calculated on the basis of served area according to the following equation:-

$$E = E_{Rate}\, A_{surface}\, T \qquad (3)$$

where; $E, E_{Rate}, and\ A_{Surface}$ are the evaporation losses ($m^3/d/served\ area$), the evaporation rate (m/d) for the study area, and top water surface area subjected to the evaporation ($m^2/served\ area$). Travel time (T) represents the consumed time in days for water to move from the beginning (point A) to the end ($point\ B$) of mesqa or marwa's length (L) through the served area (see Figure 6). Top water surface area ($A_{Surface}$) and travel time (T) can be calculated from the following equation:

$$A_{surface} = \frac{WL}{cos\alpha}, T = \frac{L}{V} \qquad (4)$$

where; $W, and\ L$ are the top water width (m) for opened water section, and mesqa or marwa length (m) per served area, respectively as illustrated in Figure 6. Velocity (V) represents the flow velocity through the cross section of mesqa or marwa. Due to small value of the inclined angle for the bed slope (α), so the term $\cos\alpha$ is assumed to equals one. For the top water width (W), two scenarios for the calculated top water surface area were considered.

Scenario (1):

Through this scenario the water level along mesqa or marwa is assumed to be full water supply level with total water depth (d) which represents small abstraction from beneficiaries. This scenario refers to the case of maximum evaporation losses by using maximum top water width (W_{Max}).

Scenario (2):

Through this scenario it is assumed large abstraction from beneficiaries, so the water depth along mesqa or marwa is assumed to be the half ($d/2$). This scenario refers to the case of the expected average evaporation losses through the mesqa or marwa length (L).

Inasmuch as the previous calculated evaporation losses in equation 3 is determined for mesqa or marwa length (L) through the served area, so there is a need to define the expected mesqa or marwa lengths per served area. Due to gained experience of the author from working in the design of on-farm improved irrigation system in Egypt at governorates of Assuit, Sohag, and Quena for about 16000 $feddan$, the following data were concluded:

- Average mesqa length per feddan is about 10 m
- Average marwa length per feddan is about 30 m

About the evaporation rate (E_{Rate}) in Egypt, there is great disparity in its values. The Egyptian Ministry of Water Resources and Irrigation adopted the minimum, average, and maximum annual evaporation rate at the level of the entire Egypt with 3.95, 7.54, and 10.8 mm/day [22, 23]. For Lake Nasser at Upper Egypt, the average annual evaporation rate is about 6.3 mm/day [24]. The range of the evaporation rates in Egypt is between 7.0 mm/day in Upper Egypt, and 4.0 mm/day for Northern Mediterranean coast [25]. Evaporation rate varies in January from 3.6 mm/day in Aswan to 7.9 mm/day in Dakhla Oasis, and in June from 14.0 mm/day in the Bahariya Oasis to 24.3 mm/day in the Dakhla Oasis [26]. The author adapted average evaporation rate of 7.54 mm/day for the entire improved on-farm irrigation system in Egypt based on the values mentioned in [22, 23].

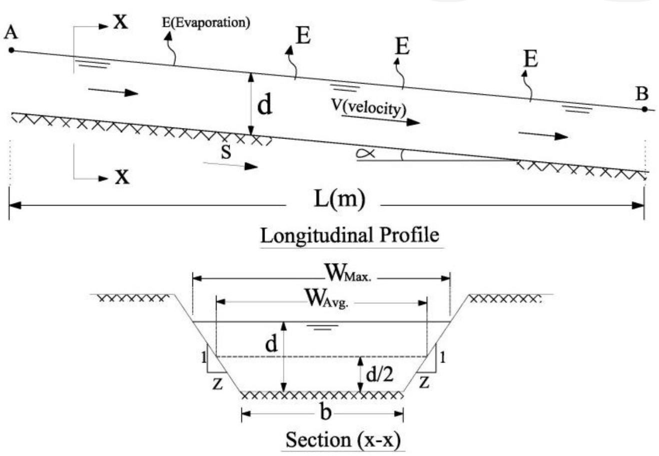

Figure 6: Main variables in the evaporation's calculations

The main procedures that are used to calculate the evaporation losses can be summarized as follows:-

(a) Assume value for the served area in feddan (A_S) for the improved on-farm system,
(b) Calculate the expected mesqa or marwa discharge (Q) using equation 1,
(c) Calculate the expected length of Mesqa or Marwa (L) in meter using the previous values of the average mesqa/marwa length per $feddan$,
(d) Calculate the water depth (d) from equation 2a, using all design parameters such as; type of cross section (earthen, lined, concrete section), bed width (b), Manning coefficient (n), longitudinal slope (S), and section side slope (Z),
(e) Calculate the flow velocity (V) from equation 2b, and calculate the maximum and average top water width ($W_{Max.}, W_{Avg.}$) according to scenario 1, and 2.
(f) Calculate the top water surface area ($A_{Surface}$) and the travel time (T) from equation 4,
(g) Apply in equation 3 to calculate the evaporation losses form mesqa or marwa lengths according to the served area.
(h) Repeat the previous steps for other values of served area (A_S), different design parameters (in item d) and for the existing and alternatives of improved on-farm irrigation system.

For time saving for the previous steps, Matlab code was developed to design various cross sections at the same time using Manning equation (item d) instead of individual design for each cross section using existing design programs such as Flow Master. Matlab code was calibrated and it gave typical results with Flow Master Program.

5.1.1 Sensitivity Analysis for Evaporation Losses

Based on the previous procedures for the calculation of evaporation losses, there are various parameters affecting the values of the evaporation losses such as; cross section type (earth, lined, and concrete), area served (A_S), Manning coefficient (n), longitudinal slope (S) of mesqa/ marwa, side slope (Z), bed width and water depth (d) for mesqa/marwa cross section. In this section, a sensitivity analysis for the design parameters will be studied. Table 2 illustrates the different assumed values for the design parameters in order to study the sensitivity analysis of these variables on the calculated evaporation losses for each section type either earthen, lined, or concrete section.

For each section type, all combinations for all different values of the design parameters are studied and the corresponding evaporation losses for each assumed served area was calculated. The evaporation losses were determined for the scenarios (1, and 2) and the results were plotted and fitted to the best fitting equations. For example Figure 7 illustrates the results for scenario 1 with maximum evaporation losses of earthen mesqa for different longitudinal slopes (S) and constant side slope of 2:1 and manning coefficient of 0.035.

Table 2: Assumed values for the sensitivity analysis of the design parameter at improved on-farm irrigation system

Item	Existing Situation	Improved on-farm irrigation system	
	Earth cross section	Lined section	Concrete section
Served area per Mesqa (fed.)	30 to 160		
Served area per Marwa (fed.)	10, 20		
Bed width for Mesqa(b) (m)	0.7, 0.8, 0.9, 1.0		
Bed width for Marwa (b) (m)	0.2, 0.3, 0.4, 0.5		
Longitudinal slope (cm/km)	20, 30, 40	20, 30, 40	20, 30, 40, 50, 60
Section side slope (H:V)	2:1 , 3:2	1:1 , 1.25:1	0:1
Manning coefficient (n)	0.028, 0.03, 0.035	0.012, 0.015, 0.017	0.011, 0.017, 0.025

From Figure 7 it is obvious that the best fitting equation is power equation as follows:

$$E = \alpha A_s^{\beta} \quad (5)$$

where; E is the evaporation per served area in cubic meter per day (m^3/d). $\alpha, and\ \beta$ are coefficients related to the fitting equation to get higher regression coefficient (R^2). The evaporation losses for all section types are following the same shape of equation 5, and the coefficients $\alpha, and\ \beta$ for different mesqa cross sections can be summarized in Table 3 for the two scenarios 1, and 2. Also Table 4 illustrates the daily maximum and average evaporation losses from different marwa cross sections per served area.

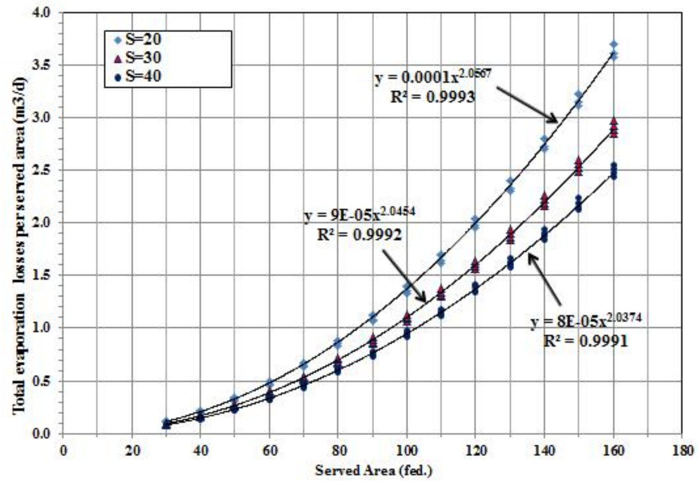

Figure 7: Evaporation losses per served area for earthen mesqa (n=0.035, Z=2) - Scenario 1

Table 3: Coefficients for evaporation losses per served area from earthen, lined, and concrete Mesqa sections for Scenario 1, and 2

Slope (S) (cm/km)	Constants	Scenario number	Earth Mesqa						Lined Mesqa						Elevated concrete Mesqa		
			n=0.028		n=0.03		n=0.035		n=0.012		n=0.015		n=0.017		n=0.011	n=0.017	n=0.025
			Z=2:1	Z=1.5:1	Z=2:1	Z=1.5:1	Z=2:1	Z=1.5:1	Z=1:1	Z=1.25:1	Z=1:1	Z=1.25:1	Z=1:1	Z=1.25:1			
20	α	1	0.00009	0.00008	0.00009	0.00009	0.0001	0.0001	0.00005	0.00005	0.00005	0.00005	0.00006	0.00006	0.00006	0.00008	0.00009
		2	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.00008	0.00008	0.00009	0.00009	0.0001	0.0001	0.0001	0.0001	0.0002
	β	1	2.0443	2.0235	2.048	2.0279	2.0567	2.0374	1.9191	1.9402	1.9383	1.9623	1.9498	1.9706	1.7192	1.7435	1.7722
		2	1.9547	1.9258	1.9597	1.9314	1.9719	1.9435	1.8121	1.8337	1.8301	1.856	1.8414	1.8643	1.6418	1.6594	1.6834
30	α	1	0.00007	0.00007	0.00008	0.00007	0.00009	0.00008	0.00004	0.00004	0.00005	0.00005	0.00005	0.00005	0.00006	0.00007	0.00008
		2	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.00008	0.00008	0.00009	0.00008	0.00009	0.00009	0.0001	0.0001	0.0002
	β	1	2.0328	2.0097	2.0369	2.0145	2.0454	2.026	1.8978	1.9216	1.9192	1.942	1.9311	1.9531	1.7019	1.7294	1.7568
		2	1.9394	1.9091	1.9447	1.9149	1.9562	1.9295	1.7927	1.816	1.8121	1.8355	1.8232	1.8465	1.6303	1.6488	1.6701
40	α	1	0.00007	0.00006	0.00007	0.00007	0.00008	0.00007	0.00004	0.00004	0.00004	0.00004	0.00005	0.00005	0.00005	0.00006	0.00008
		2	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.00007	0.00007	0.00008	0.00008	0.00008	0.00008	0.0001	0.0001	0.0001
	β	1	2.0255	1.9993	2.0283	2.0043	2.0374	2.0152	1.8838	1.9082	1.9054	1.929	1.9174	1.9403	1.6937	1.7199	1.7463
		2	1.9302	1.8971	1.9337	1.9029	1.9455	1.9157	1.7806	1.8037	1.7995	1.8229	1.8104	1.8338	1.6253	1.642	1.6616
50	α	1													0.00005	0.00006	0.00007
		2													0.00009	0.0001	0.0001
	β	1													1.6876	1.7128	1.7384
		2													1.6218	1.6372	1.6554
60	α	1													0.00005	0.00006	0.00007
		2													0.00009	0.0001	0.0001
	β	1													1.6828	1.7072	1.7321
		2													1.6192	1.6336	1.6507

Table 4: Evaporation losses (m^3/day) from earthen, lined, and concrete marwa sections for scenario 1, and 2

Slope (S) (cm/km)	Constants	Scenario number	Earth Mesqa						Lined Mesqa						Elevated concrete Mesqa		
			n=0.028		n=0.03		n=0.035		n=0.012		n=0.015		n=0.017		n=0.011	n=0.017	n=0.025
			Z=2:1	Z=1.5:1	Z=2:1	Z=1.5:1	Z=2:1	Z=1.5:1	Z=1:1	Z=1.25:1	Z=1:1	Z=1.25:1	Z=1:1	Z=1.25:1			
20	10	1	0.0713	0.0599	0.0767	0.0643	0.0901	0.0753	0.0217	0.0238	0.0266	0.0294	0.0300	0.0331	0.0125	0.0172	0.0231
		2	0.0712	0.0618	0.0760	0.0659	0.0882	0.0761	0.0255	0.0273	0.0306	0.0329	0.0340	0.0367	0.0171	0.0227	0.0295
	20	1	0.3066	0.2532	0.3305	0.2728	0.3910	0.3222	0.0834	0.0933	0.1046	0.1175	0.1190	0.1338	0.0383	0.0544	0.0753
		2	0.2814	0.2378	0.3020	0.2549	0.3539	0.2979	0.0874	0.0958	0.1073	0.1181	0.1206	0.1330	0.0478	0.0656	0.0878
30	10	1	0.0578	0.0488	0.0621	0.0518	0.0729	0.0612	0.0180	0.0197	0.0221	0.0242	0.0248	0.0273	0.0108	0.0148	0.0198
		2	0.0588	0.0513	0.0627	0.0546	0.0726	0.0630	0.0217	0.0231	0.0259	0.0278	0.0287	0.0308	0.0150	0.0199	0.0257
	20	1	0.2462	0.2038	0.2653	0.2175	0.3135	0.2589	0.0680	0.0759	0.0851	0.0953	0.0966	0.1084	0.0326	0.0461	0.0634
		2	0.2290	0.1943	0.2456	0.2072	0.2873	0.2428	0.0729	0.0795	0.0891	0.0976	0.0999	0.1097	0.0415	0.0565	0.0752
40	10	1	0.0499	0.0422	0.0536	0.0452	0.0628	0.0523	0.0159	0.0173	0.0194	0.0212	0.0216	0.0238	0.0098	0.0133	0.0177
		2	0.0514	0.0451	0.0548	0.0479	0.0633	0.0551	0.0194	0.0205	0.0231	0.0246	0.0252	0.0273	0.0137	0.0181	0.0233
	20	1	0.2109	0.1749	0.2271	0.1882	0.2683	0.2196	0.0590	0.0657	0.0736	0.0823	0.0835	0.0935	0.0292	0.0411	0.0562
		2	0.1981	0.1687	0.2123	0.1805	0.2482	0.2091	0.0642	0.0698	0.0782	0.0855	0.0870	0.0960	0.0376	0.0510	0.0675
50	10	1													0.0091	0.0123	0.0163
		2													0.0127	0.0168	0.0217
	20	1													0.0268	0.0376	0.0513
		2													0.0348	0.0471	0.0622
60	10	1													0.0085	0.0115	0.0152
		2													0.0120	0.0159	0.0204
	20	1													0.0250	0.0355	0.0476
		2													0.0327	0.0447	0.0581

5.1.2 Statistical Analysis for Evaporation losses

From the previous tables, the ultimate minimum and maximum evaporation losses for mesqa and marwa per served area can be extracted from Tables 3 and 4. Table 5 summarized the coefficients for minimum and maximum evaporation losses per served area for different mesqa cross sections; also Table 6 illustrates the same losses for different marwa cross sections. The served area for one marwa can be estimated to be 15 $feddan$, and the minimum and maximum evaporation losses at this served area can be interpolated as illustrated in Table 6.

Table 5: Coefficients for minimum and maximum evaporation losses per served area (m^3/day) for different mesqa cross sections.

Constant	Earthen Mesqa		Lined Mesqa		Concrete Mesqa	
	Min. losses	Max. losses	Min. losses	Max. losses	Min. losses	Max. losses
α	0.0001	0.0001	0.00007	0.0001	0.00009	0.0001
β	1.8971	2.0567	1.7806	1.9706	1.6192	1.7722

Table 6: Minimum and maximum daily evaporation losses per served area (m^3/day) for different marwa cross sections.

Served area (fed.)	Earthen Mesqa		Lined Mesqa		Concrete Mesqa	
	Min. losses	Max. losses	Min. losses	Max. losses	Min. losses	Max. losses
10	0.0422	0.0901	0.0159	0.0367	0.0085	0.0295
20	0.1687	0.3910	0.0590	0.1338	0.0250	0.0878
15	**0.1055**	**0.2406**	**0.0375**	**0.0853**	**0.0168**	**0.0587**

5.1.3 Total Evaporation losses per served area

Each served area at on-farm system contains one main mesqa and different marwas branches. So, this section discusses the calculation of the total evaporation losses per the total served area including mesqa and marwas losses. The calculations are based on the following criteria:

- The served area (A_S) in feddan for the entire improved on-farm irrigation system is assumed to be varied with different values (30, 40, $\ldots etc$)
- The following items are calculated for marwas; the total required number of marwas per every served area, minimum and maximum total evaporation losses from all expected marwas using values from Table 6 according to the section type.
- The total minimum/maximum evaporation losses from mesqa are calculated using Table 5
- The total summation of minimum and maximum evaporation losses from both marwas and mesqa per each served area are detected; also the total average evaporation losses are determined.

For the previous concept, the total evaporation losses for the whole served area (due to its two main components mesqa and marwas) can be calculated and plotted with fitting equations for different mesqa/ marwa cross section as shown in Figures 8a to c . Through these figures, fitting equations are developed for each cross section to determine the total minimum, average, and maximum evaporation losses per each served area.

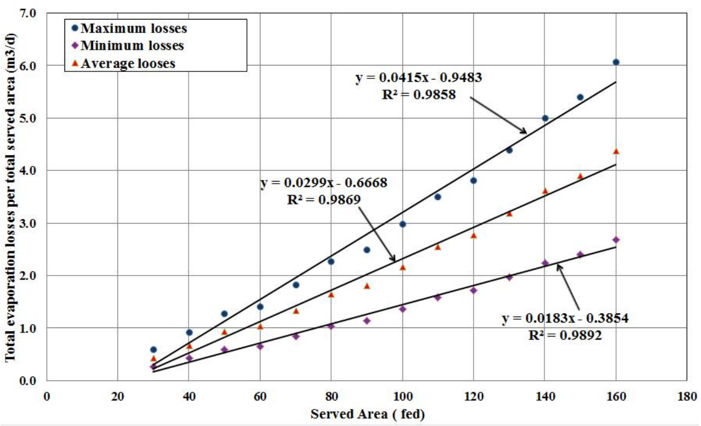

Figure 8a: Total evaporation losses for the whole served area from earthen mesqa and marwa cross sections

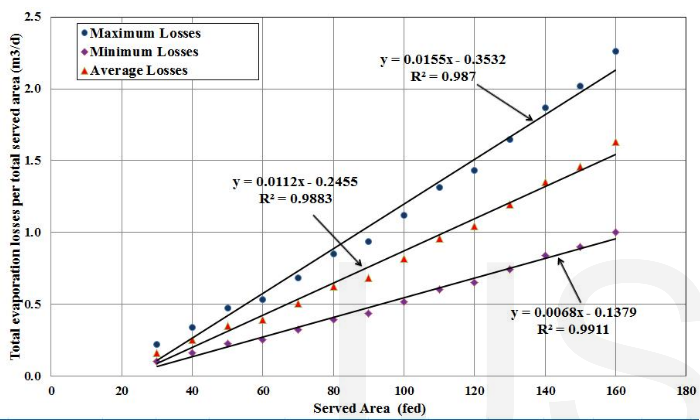

Figure 8b: Total evaporation losses for the whole served area from lined mesqa and marwa cross sections

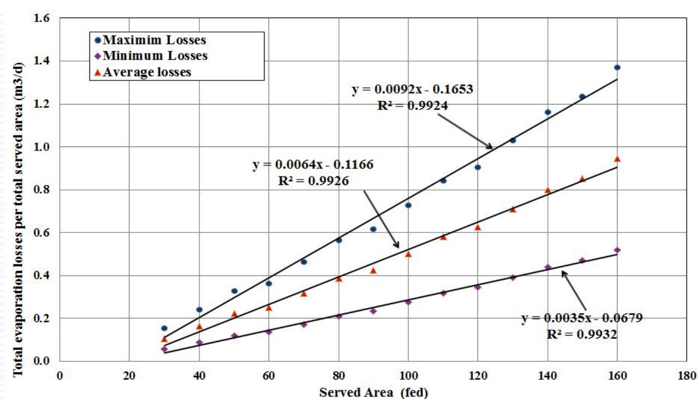

Figure 8c: Total evaporation losses for the whole served area from elevated concrete mesqa and marwa cross sections

5.2 Seepage losses

Seepage losses at on-farm irrigation system are extracted from the wetted perimeter of opened water section for meaqa and marwa. Seepage loss at steady state condition from an unlined or a cracked lined or concrete canal in a homogeneous and isotropic porous media, can be expressed as follows [27]:

$$q = KdF \tag{6}$$

where q is seepage discharge (m^3/s) per mesqa or marwa length. Parameter d is the flow depth (m) at mesqa or marwa cross section. The parameter K represents the hydraulic conductivity for the porous medium of mesqa and marwa section (m/s). The hydraulic conductivity for earthen mesqa depends on the existing soil type at improved irrigation projects. Soil type in Delta Egypt is clayey soil with hydraulic conductivity of 0.000128 cm/sec (1.28x10-6 m/sec) [28].

For cracked lined or concrete section, the hydraulic conductivity can be adapted with 1x10-6 m/sec [29]. F is the seepage function depends on the shape of the cross section [27]. For rectangular cross section with bed width (b), and water depth (d), the seepage function (F) can be expressed as in equation 7.

$$F = \left((4\pi - \pi^2)^{0.77} + \left(\frac{b}{d}\right)^{0.77}\right)^{1.33} \quad for \;\; 0 \le \frac{b}{d} \le 1000 \tag{7}$$

For trapezoidal cross section with bed width (b), water depth (d), and side slope Z: 1 (H: V), the seepage function (F) can be expressed as in equation 8.

$$F = \left(\left((\pi(4-\pi))^{1.3} + (2Z)^{1.3}\right)^{\frac{0.77+0.462Z}{1.3+0.6Z}} + \left(\frac{b}{d}\right)^{\frac{1.0+0.6Z}{1.3+0.6Z}}\right)^{\frac{1.3+0.6Z}{1.0+0.6Z}}$$

$$for \;\; 0 \le \frac{b}{d} \le 1000, \qquad 0 \le Z \le 1000 \tag{8}$$

Two scenarios for the calculated seepage losses are considered, scenario 1 and 2 as in the evaporation losses. Scenario 1 represents maximum seepage losses through considering full water depth (d), and scenario 2 illustrates minimum seepage losses through considering half water depth in mesqa/ marwa cross section. Design procedures for the cross section of mesqa/ marwa are illustrated in section 5.1.

5.2.1 Sensitivity Analysis for SEEPAGE Losses

Due to various design parameters that can affect the calculated seepage losses, a sensitivity analysis is developed using the same range of design parameters mentioned in Table 2 as example. Figure 9 illustrates the results for scenario 1 with maximum seepage losses of earthen mesqa for different longitudinal slopes (S) and constant value for side slope of 2:1 and manning coefficient of 0.035 as example. From Figure 9 it is obvious that the best fitting equation for the seepage losses is power equation as for the evaporation losses as follows:

$$I = \propto A_s^{\beta} \tag{9}$$

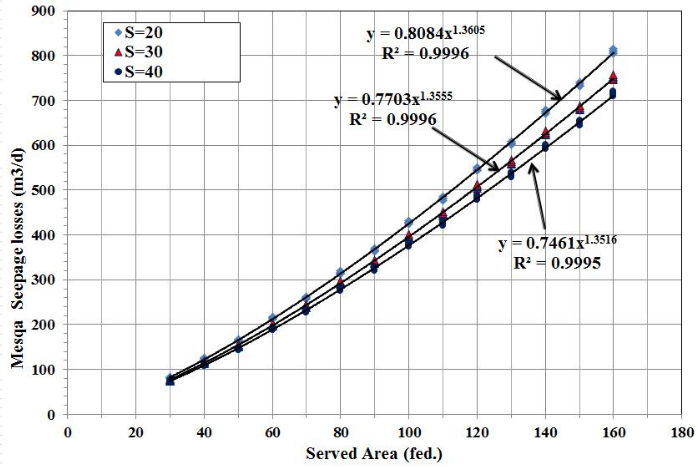

Figure 9: Seepage losses per served area for earthen mesqa (n = 0.035, Z = 2) - scenario 1

where; I is the seepage losses per served area in cubic meter per day (m^3/d). $\alpha, and\ \beta$ are the coefficients related to the fitting equation to get best regression coefficient (R^2). The seepage losses for all section types are following the same shape of equation 9, and the coefficients $\alpha, and\ \beta$ for different mesqa cross sections can be summarized in Table 7 for the two scenarios 1, and 2. Also Table 8 illustrates the daily maximum and average seepage losses from different marwa cross sections for the entire served area.

Table 7: Coefficients for seepage losses per served area from earthen, lined, and concrete Mesqa sections for Scenario 1, and 2

Slope (S) (cm/km)	Constants	Scenario number	Earth Mesqa						Lined Mesqa						Elevated concrete Mesqa		
			n=0.028		n=0.03		n=0.035		n=0.012		n=0.015		n=0.017		n=0.011	n=0.017	n=0.025
			Z=2:1	Z=1.5:1	Z=2:1	Z=1.5:1	Z=2:1	Z=1.5:1	Z=1:1	Z=1.25:1	Z=1:1	Z=1.25:1	Z=1:1	Z=1.25:1			
20	α	1	0.7516	0.7241	0.779	0.7347	0.8084	0.7604	0.4741	0.4851	0.483	0.4997	0.487	0.5043	0.3938	0.3561	0.3264
		2	0.693	0.6677	0.6927	0.672	0.7055	0.6826	0.491	0.4963	0.4903	0.4988	0.491	0.4963	0.4481	0.3973	0.354
	β	1	1.3368	1.3546	1.3568	1.3568	1.3605	1.3612	1.3193	1.3198	1.3312	1.3309	1.3497	1.3363	1.369	1.4318	1.4924
		2	1.2623	1.2781	1.2837	1.281	1.2894	1.2871	1.2352	1.2364	1.2476	1.2487	1.2352	1.2364	1.2705	1.3218	1.3862
30	α	1	0.7235	0.696	0.7445	0.7051	0.7703	0.736	0.4688	0.4777	0.4748	0.486	0.4757	0.492	0.4123	0.3732	0.3415
		2	0.6821	0.6571	0.6783	0.6604	0.689	0.6742	0.493	0.4973	0.4909	0.4963	0.493	0.4973	0.4717	0.4208	0.3764
	β	1	1.3306	1.3479	1.3513	1.3503	1.3555	1.3543	1.3077	1.3091	1.3204	1.3208	1.3395	1.327	1.3419	1.4017	1.46
		2	1.2542	1.2694	1.2759	1.2725	1.2819	1.2786	1.2236	1.2254	1.2363	1.2374	1.2236	1.2254	1.2466	1.3002	1.3549
40	α	1	0.7105	0.678	0.7227	0.6867	0.7461	0.7065	0.4664	0.4738	0.4706	0.4803	0.4695	0.4852	0.4256	0.3858	0.3529
		2	0.6783	0.6512	0.669	0.6539	0.679	0.6609	0.496	0.4989	0.4923	0.4967	0.496	0.4989	0.4883	0.4377	0.3928
	β	1	1.3256	1.3427	1.347	1.3453	1.3516	1.3507	1.2991	1.3011	1.3123	1.3133	1.3317	1.3198	1.3237	1.3812	1.4378
		2	1.2484	1.263	1.2701	1.2661	1.2763	1.2729	1.2153	1.2175	1.2282	1.2297	1.2153	1.2175	1.2308	1.2816	1.3337
50	α	1													0.436	0.3958	0.3621
		2													0.5009	0.4507	0.4056
	β	1													1.31	1.3658	1.4209
		2													1.2191	1.2677	1.3179
60	α	1													0.4446	0.4041	0.3699
		2													0.5112	0.4614	0.4163
	β	1													1.2992	1.3536	1.4074
		2													1.2099	1.2569	1.3055

Table 8: Seepage losses (m^3/day) from earthen, lined, and concrete marwa sections for scenario 1, and 2

Slope (S) (cm/km)	Constants	Scenario number	Earth Mesqa						Lined Mesqa						Elevated concrete Mesqa		
			n=0.028		n=0.03		n=0.035		n=0.012		n=0.015		n=0.017		n=0.011	n=0.017	n=0.025
			Z=2:1	Z=1.5:1	Z=2:1	Z=1.5:1	Z=2:1	Z=1.5:1	Z=1:1	Z=1.25:1	Z=1:1	Z=1.25:1	Z=1:1	Z=1.25:1			
20	10	1	43.52	41.07	44.55	131.38	46.98	138.93	23.14	23.71	24.82	25.42	25.83	26.46	24.45	29.34	35.41
		2	28.34	27.18	28.87	27.69	30.13	28.88	16.65	16.91	17.54	17.81	18.07	18.35	18.01	20.63	23.86
	20	1	128.15	121.12	42.04	124.20	44.34	131.40	66.67	68.14	72.19	73.71	75.53	77.07	82.36	107.23	139.15
		2	77.79	74.50	79.44	76.08	83.30	79.78	44.01	44.65	46.89	47.54	48.62	49.28	53.80	66.84	83.44
30	10	1	40.63	38.35	41.59	122.12	43.82	129.09	21.77	22.30	23.29	23.85	24.21	24.80	22.68	26.85	31.98
		2	26.85	25.77	27.34	25.46	28.50	27.33	15.93	16.17	16.73	16.99	17.22	17.48	17.06	19.30	22.04
	20	1	119.13	112.54	37.73	112.00	41.35	122.02	62.10	63.52	67.15	68.63	70.21	71.71	73.66	94.45	120.97
		2	73.17	70.08	74.70	69.82	78.27	74.96	41.62	42.24	44.26	44.90	45.85	46.50	49.21	60.15	74.00
40	10	1	38.73	36.57	39.63	115.98	41.73	122.57	20.87	21.37	22.29	22.83	23.63	23.72	21.58	25.31	29.87
		2	25.87	24.84	26.33	25.28	27.42	25.43	15.45	15.68	16.20	16.45	16.91	16.91	16.46	18.47	20.91
	20	1	113.16	106.87	37.41	109.55	37.67	111.81	59.10	60.48	63.84	65.28	68.09	68.18	68.35	86.68	109.98
		2	70.11	67.16	71.56	68.54	74.94	69.72	40.05	40.66	42.53	43.16	44.75	44.67	46.40	56.08	68.27
50	10	1													20.80	24.23	28.41
		2													16.05	17.90	20.13
	20	1													64.65	81.31	102.39
		2													44.44	53.25	64.31
60	10	1													20.21	23.42	27.30
		2													15.73	17.46	19.54
	20	1													61.88	77.28	96.73
		2													42.96	51.13	61.35

5.2.2 Statistical Analysis for SEEPAGE losses

From Tables 7 and 8, the ultimate minimum and maximum seepage losses for mesqa and marwa per served area can be extracted. Table 9 summarized the coefficients for minimum and maximum seepage losses per served area from mesqa section; also Table 10 illustrates the same losses for marwa section. The served area for one marwa can be estimated to be 15 $feddan$, and the minimum and maximum seepage losses at this served area can be interpolated as illustrated in Table 10.

Table 9: Coefficients for minimum and maximum seepage losses per served area (m^3/day) for different mesqa cross sections.

Constant	Earthen Mesqa		Lined Mesqa		Concrete Mesqa	
	Min. losses	Max. losses	Min. losses	Max. losses	Min. losses	Max. losses
α	0.6783	0.8084	0.496	0.487	0.5112	0.3529
β	1.2484	1.3605	1.2153	1.3497	1.2099	1.4378

Table 10: Minimum and maximum daily seepage losses per served area (m^3/ day) for different marwa cross sections.

Served area (fed.)	Earthen Mesqa		Lined Mesqa		Concrete Mesqa	
	Min. losses	Max. losses	Min. losses	Max. losses	Min. losses	Max. losses
10	24.8434	138.9337	15.4512	26.4582	15.7269	35.4120
20	67.1591	131.4006	40.0522	77.0744	42.9622	139.1529
15	46.00	135.17	27.75	51.77	29.34	87.28

5.2.3 Total seepage losses per served area

By following the same concept illustrated in section 5.1.3, the total seepage losses from the entire served area including mesqa and marwas can be calculated. The total minimum, average, and maximum seepage losses from the whole served area with best fitting equations are illustrated in Figures (10a) to (10c).

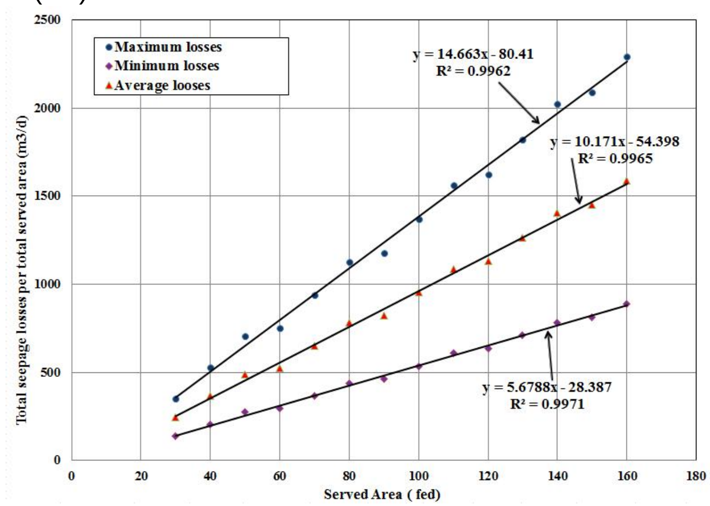

Figure 10a: Total seepage losses for the whole served area from earthen mesqa and marwa cross sections

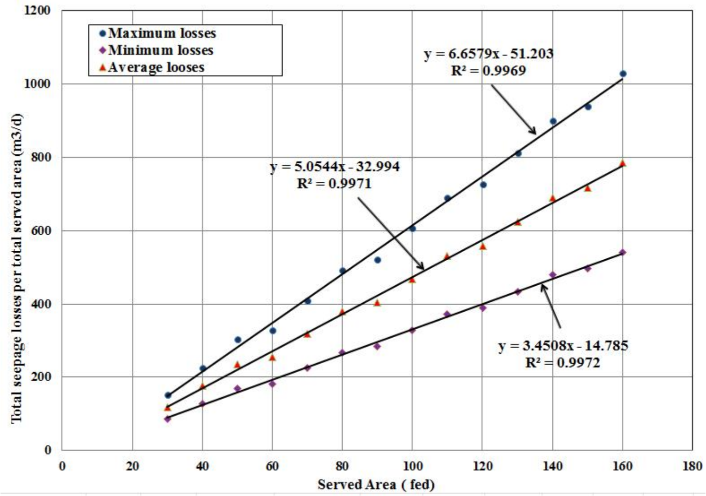

Figure 10b: Total seepage losses for the whole served area from lined mesqa and marwa cross sections

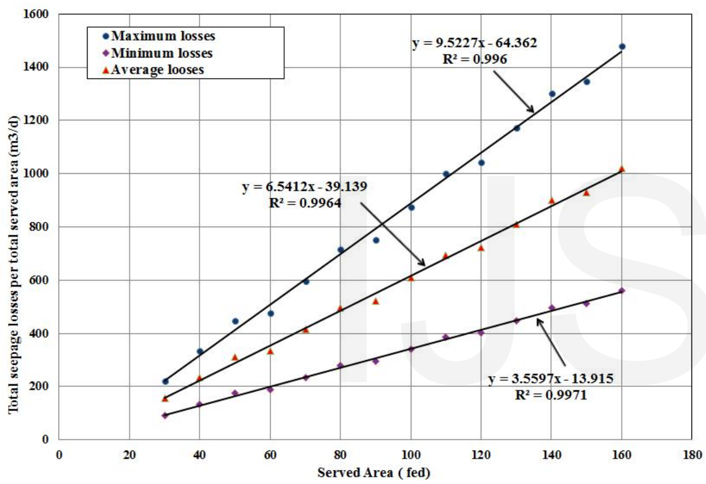

Figure 10c: Total seepage losses for the whole served area from concrete mesqa and marwa cross sections

6 Total water saving from improved on-farm irrigation system in Egypt

Egypt had approximately 80,000 km of mesqas and irrigation ditches (marwas) [30]. At the beginning of improved on-farm irrigation project, 60% and 40% of earthen mesqa was improved to be low pressure pipeline, and lined section, respectively [31]. The farmers did not agree on such percentages due to their preference for the pipelines system, so the final designs made for about 90% for pipeline system, 4% for lined section, and 6% for elevated concrete section. According to these final percentages, the total expected water saving from evaporation and seepage losses are calculated based on the following concept:

- Average mesqa length per feddan is $10\,m$ and marwa length per feddan is $30\,m$.
- For common served area of marwa of $15\,feddan$, the length for one marwa is 450 m.
- The total number of requires marwas per served area can be detected, and accordingly the total lengths of marwas can be calculated. Then the total lengths of mesqa and marwas per served area (L_t) can be determined.
- For the calculation of annual water losses, water is considered to be available at on-farm system for about 10 month per year, and there are two months for maintenance (Called "Sadda Shetwaya").

6.1 Evaluation of the current condition

Current water losses at on-farm system in Egypt are large due to using earthen cross section of mesqa and marwa. Through the following paragraph, the existing water losses (evaporation and seepage) at on-farm system will be determined to be the base for the calculation of the expected water saving from improved on-farm irrigation projects.

The existing situation at on-farm level is assumed to be divided into two parts, legal and illegal irrigation methods which are reflected on the lengths and area served by mesqa and marwas. The existing legal earth mesqas are assumed to be with average served area of 60 $feddan$ for about 10% of the total existing lengths of mesqa and marwas in Egypt (L_1 = 8,000 km). The remaining existing earth mesqas are assumed to be illegal that use direct irrigation from main and secondary canals with served area of about 100 $feddan$ for total mesqa and marwas lengths of about (L_2 = 72,000 km).

The total lengths of mesqas for served area of 60 and 100 feddan are 600 and 1000m, respectively (see section 6). Due to that the total marwas lengths for 15 $feddan\ is$ 450 m (see section 6), so the total marwas lengths for the served are of 60 and 100 $feddan$ are about 1800 and 3150m, respectively. The total mesqa nad marwas lengths (L_t) for served area of 60 and 100 are 2400 and 4150 m, respectively.The expected total existing number of served area (N) for either served area of 60 or 100 $feddan$ can be detected by dividing L_1 , and L_2 by total lengths per each served area (L_t), respectively. So the total number of served area for 60 and 100 $feddan$ are about 3334 and 17350, respectively (see Table 11).Then the developed equations for the evaporation and seepage losses per served area can be applied (see Figures 8a, and 10a) to calculate the total losses as in Table 11. From this table, the total minimum, maximum, and average annual losses from the existing on-farm irrigation system in Egypt (due to earth cross sections) are 3.13, 8.03, and 5.58 BCM, respectively.

Table 11: Current water losses from original on-farm irrigation system in Egypt (earth cross sections)

Served area (fed.)	Lt (m)	Number of served area in Egypt (N)	Evaporation losses (MCM/year)			Seepage losses (BCM/year)		
			Min.	Max.	Avg.	Min.	Max.	Avg.
60	2400	3334	0.71	1.54	1.13	0.31	0.80	0.56
100	4150	17350	7.52	16.66	12.09	2.81	7.21	5.01
Total			**8.23**	**18.21**	**13.22**	**3.12**	**8.01**	**5.57**

6.2 Expected saving from improved on-farm irrigation system

For improved pipeline system at on-farm system there is no either evaporation or seepage losses except at junctions. If there is an intension from the Ministry of Water Resources and Irrigation to apply the same percentages of the development sections; pipeline, lined, and concrete section for the entire existing areas of on-farm system in Egypt, that means at least about 90% of the previous losses will be saved due to using pipeline system. Evaporation and seepage losses will come only from the expected improved lined section (4%) and concrete section (6%) as shown in Table 12. It is assumed that the average served area for lined and concrete sections to be 60, and 90 $feddan$, respectively.

Table 12: Water losses from improved on-farm irrigation system in Egypt (lined / concrete section)

Improved section	Served area (fed.)	Lt (m)	No. of served area in Egypt (N)	Evaporation losses (MCM/year)			Seepage losses (BCM/year)		
				Min.	Max.	Avg.	Min.	Max.	Avg.
Lined	60	2400	1334	0.11	0.23	0.17	0.10	0.17	0.13
Concrete	90	3600	1334	0.10	0.27	0.18	0.15	0.40	0.26
Total				**0.21**	**0.50**	**0.35**	**0.25**	**0.57**	**0.39**

From Table 12, the total minimum, maximum, and average annual losses from the improved on-farm irrigation projects in Egypt (due to lined and concrete sections) are 0.25, 0.57, and 0.39 BCM, respectively. So the expected theoretical water saving from completed improved on-farm irrigation projects in Egypt is the difference between water losses in Table 11 and 12. But there are other losses that should be taken into consideration which is seepage losses at junctions and fitting due to multiple joints. This type of losses is assumed to be 10% of the theoretical water saving. Finally the expected minimum, maximum, and average annual water saving from improved on-farm irrigation projects are the summation of water saving from evaporation and infiltration losses which are about 2.6, 6.72, and 4.67 BCM, respectively as illustrated in Table 13.

Table 13: Water saving from improved on-farm irrigation projects in Egypt

Item	Evaporation (MCM/year)			Seepage (BCM/year)		
	Min.	Max.	Avg.	Min.	Max.	Avg.
Theoretical water saving	8.02	17.71	12.87	2.87	7.44	5.18
Junction's losses (10%)	0.802	1.771	1.287	0.29	0.74	0.52
Expected Water saving	**7.22**	**15.94**	**11.58**	**2.58**	**6.70**	**4.66**

7 Conclusions

This paper discussed the expecetd water saving from improved on-farm irrigation projects in Egypt. Through this paper, two main water losses at on-farm system were discussed; evaporation and seepage losses. Through each type of losses, the following was done:-

- Creating Matlab code to design three different cross sections; earth, lined, and concrete and it was calibrated from Flow Master with good results.
- Sensitivity analysis was developed for most of the design parameters to study its effect on the calculated losses either evaporation or seepage losses.
- Statistical analysis was discussed to detect the minimum, maximum losses on the level of mesqa and marwa.
- Approximate equations were developed to calculate evaporation and seepage loses per served area for mesqa and marwa separately. Then approximate equations were developed to calculate the expected total evaporation and seepage losses per served area including losses from mesqa and marwas together.

So, finally this paper presented guideline equations that can be used to calculate the expected water losses due to evaporation and seepage from on-farm irrigation system in Egypt. It is concluded from this paper that the expected minimum, maximum, and average annual water saving from the whole improved on-farm irrigation projects in Egypt are about $\mathbf{2.6}$, $\mathbf{6.72}$, $\boldsymbol{and}$ $\mathbf{4.67}$ $\boldsymbol{BCM}$, respectively.

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