Comparative Technical study for Estimating Seeped Water from Irrigation Canals in Middle Egypt

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ABSTRACT

Integrating with the national project of irrigation canals lining in the Egyptian countryside, the present study is introduced. The study presents a technical comparative reading in different theories and equations usually used for estimating the quantities of water that seep from the earthen irrigation canals. The quantities of the irrigation water lost due to seepage are great enough to decrease the wide gap between the needed and available quantities of water that Egypt seriously suffers from. The accurate estimation of water quantities that may seep, or leak enables the decision maker to choose the perfect method for making use of such quantities and where it may be used. From Assiut countryside the El-Sont branch canal and its off-takings was chosen to be our case study. After a careful engineering, technical reading in seepage equations that researchers introduced previously, the closest relationships to our case study were used. Results indicated that, using the suggested relationship by nazir Ahmed [1], and the Indian equation [2] gave the maximum seepage quantities for the entire El-Sont canal network. This seeped water represents about 21.5% of the total canal head discharge. Most of this lost water can be saved due to the implementation of the national project of irrigation canals lining.

Keywords: Water Saving- Irrigation Canals- Irrigation rotations- Seepage Losses.

1. INTRODUCTION

Nowadays, Egypt facing a serious challenge to bridge the large gap between the required and limited available amount of irrigation water. Also, to secure the increasing demand of agricultural production and food, to meet the rapid growth in the population. This is the reason for the speedy implantation of the National Project for Lining and Rehabilitation of the irrigation canals all over the Egyptian Countryside. Also, to preserve the huge amount of water that is wasted through seepage from the water cross-section of canals to the permeable soil in which they were dug. The total length of irrigation canals in Egypt exceeds 33.5 thousand kilometers in 20 governorates without the border governorates. The expected quantity of saved water is about 5 billion cubic meters per year [3] which is so good, gained quantity of water expected from such great National project, beside other valuable gains expected in the environment, health, and social sectors.

The transfer and distribution process of irrigation water through open canal networks is considered the most important reason of causing the irrigation water loses, for different fundamental reasons as follows, (i) The nature of the soil in which such open canals are dug; (ii) The large lengths of these network canals; (iii) Hot weather and humidity degree; (iv) Design and geometry of those waterways; (v) Bad and irresponsible handling and dealing with water; (vi) Don't care of periodic maintenance and follow-up of these waterways and, (vii) The inappropriate level of community and environmental awareness of the seriousness of water issues, and their impacts on all aspects of the life.

Among the above-mentioned reasons causing irrigation water loses, the nature of soil in which open irrigation canals are dug, is the main reason causing the greatest amount of water loses. Since all the Egyptian land was created through the history, along thousands of years by the sediments carried by the great River Nile, forming the permeable deep layers in which all Egyptian activates, and civilization were carried out and established on. So, all the Egyptian irrigation open channel networks were dug in such a permeable soil of different permeability coefficients, ranges from smallness in the clayey soil close to the river stream, to larger values as we move away from the river to the east and to the west, where the sandy desert soil of highly permeability coefficient. The amount of seepage loss to the surrounding area varies from section to section depending on soil permeability; length and shape of canal wetted perimeter; depth of water in the canal; flow rate and velocity; location of ground water table; constructions on ground water flow, e.g. Presence of wells, rivers, drains, impermeable boundaries, etc.; soil suction in zone between ground water level and ground level; viscosity of water (can be neglected); salinity of water; sediment load and size distribution, and canal age [4], [5], and [6].

The main aim of the present study is to survey the most popular and famous relationships introduced, in the literature, for accurate estimation of the expected quantities of seeped water. To compere between them, for knowing the most accurate and close, or in good similar to the Egyptian case, to be under our eyes while estimating the expected gained of such seeped water from the Egyptian irrigation canals network all over the Egyptian countryside.

2. LITERATURE REVIEW

By reviewing the previous research activities and studies carried out concerning the rates of seepage water through different types of permeable soil and estimating its quantities, it was found the great richness and diversity that covered all the involved technical parameters.

2.1) Canal Seepage Losses

Martin [7] stated that seepage losses can account for 20-30% of the total flow volume in unlined earthen canals. This ratio was confirmed by Kulkarni [8] who reported that in India about 20-25% of water losses occur in unlined watercourses. Kacimov [9] stated that seepage losses from channels for several irrigation systems in the former U.S.S.R. (Union of Soviet Socialist Republics) amount up to 40-50% of the transported water quantity.

Robinson, [10] and Alam [5] reported that seepage rate can be evaluated by three methods: direct (field) measurement methods, empirical formulas, and analytical equations. Famous field tests for measuring seepage are inflow–outflow method, ponding tests method, seepage meter method, and double-ring infiltration method. Khan [2], Kraatz [11], and Dhillon [12] reviewed that the exact analysis of seepage loss from the canals is a very complex operation. Empirical formulas are based on relationships found between water losses and the hydraulic conditions. Some formulas developed for very specific, localized conditions, and others estimate more generalized situations such as unlined or lined canals; others require canal discharge/velocity or the saturated permeability of the canal soils.

Dhotre [13], Studied a field evaluation of seepage losses through channels. He concluded that, seepage losses in lined and unlined field channels were 1.64 and 3.62 $m^3/s/Mm^2$ respectively. This means lining reduced losses by 54.70% less compared to the unlined one. Tarek Sayed [14], used in his research field data which were collected through the official Ministry of Water Resources and Irrigation authority (MWRI) in Assiut governorate about the Almanna canal and its branches. His results indicated that, the lost water through only seepage reaches about 23.9% of the actual discharges that give at the head. Mowafy [15], applied different empirical formulae and analytical equations to evaluate seepage losses in the different sections of the Ismailia canal in Egypt. The results of computed seepage losses by empirical formulae of Molesworth and Yennidunia [15], Hungarian, and analytical equations gave good results when compared with different field measured results.

2.2) Most Popular Used Equations Related to Seepage Prediction

A quick review for the most important equations related to seepage prediction showed that, the use of the empirical relationships is insufficient due to the large number of involved parameters found in the equations, such as canal soil permeability, canal wetted perimeter, length and shape, canal water depth, soil or canal lining uniformity, flow rate and velocity [16]. The most famous equations introduced previously for estimating the seepage water with their affecting parameters on seepage are summarized and tabulated in the following constructed table (1)

Table 1: popular seepage equations and their affecting parameters on seepage

No.	Equation	Author	Units	Affecting Governing Parameters	Notes
1	$S = C_1 LP\sqrt{R}$	*Molesworth & Yennidunia* [15]	*m^3/s*	*Soil Type, Wetted Perimeter, Length, Water Depth, Width, Hydraulic Radius, Slope, Velocity, and Discharge*	*length in km, C1 = 0.003, 0.0015, 0.0018, 0.0022, and 0.0026 for sandy loam, clay, silty clay, clay loam, and silty loam, respectively.*
2	$S = \frac{C_2 * 10^{-4}}{R^{1.166} * i^{0.5}}$	*Molesworth & Yennidunia* [11]	*$m^3/s/km$*		*C2 =0.375 and 0.75 for clayey soil and sandy soil respectively.*
3	$S = 0.2 \times C_3 \times \sqrt{Q/V}$	*Mortiz USSR* [17]	*$ft^3/s/mil$*		*C3 = to 0.34, 0.41, 0.66, 1.68, and 2.20 for Cemented gravel and hard pan with sandy loam; Clay and Clayey Loam; Sandy Loam, Sandy soil with rock, Sandy, and gravelly soil respectively.*
4	$S = \frac{C_4 \times P \times L \times H^{1/3}}{4 \times 10^6 + 2000\sqrt{v}}$	*Davis and Wilson* [18]	*$ft^3/s/ft$*		*lining type C4 = 1, 4, 5, 6, 8, 10 for Concrete; Clay puddle or mass clay; thick new coat of crude oil or light asphalt; Cement plaster; Clay puddle; Cement grout or asphalt respectively. unlined soli type C4 = 12; 15l 20, 25; 30, 40, 50; 70 For Clay soil, Clay loam soil, medium loam, Sandy loam; Coarse sandy loam, Fine sand; medium sand; Coarse sand and gravel respectively.*
5	$S = 0.55 \times 10^{-6} C_5 PL\sqrt{H}$	*Ingham* [19]	*m^3/s*	*Soil Type, Wetted Perimeter, Length, Water Depth, Width, Slope, Velocity, and Discharge*	*C5 varies between 1.5 and 5.5.*
6	$S = C_6 aH$	*Indian* [2],	*ft^3/s*		*a in million ft^2; C6 varies from 1.1 to 1.8*
7	$S = 5 \times 10^{-6} Q^{0.0652} PL$	*Pakistani* [2]	*ft^3/s*	*Wetted Perimeter, Length, Water Depth, Width, Slope, Velocity, and Discharge*	*One soil type*
8	$S = (0.04Q^{0.68})/56.81$	*Nazir Ahmad* [1]	*$m^3/s/km$*	*Length, Discharge*	*One soil type*
9	$S = 1700 d_a H(b + H \times i)$	*Hungarian* [20]	*$m^3/day/m$*	*Soil Type, Length, Water Depth, Width, Slope, Velocity, and Discharge*	*da is the effective size diameter of the grains of the soil (mm, trapezoidal canals only*

From the above constructed table 1, there are six equations (equations 1 to 6) proved to be very close to our Egyptian soil nature and climate. So, they can be used in our case study. This is partially confirmed with Mowafy 2001 [15] who recommend computing seepage losses in Egyptian canals by the Molesworth and Yennidunia [15] and Molesworth & Yennidunia [11] equations (Number 1 and 2 in table 1). On the other side, it is noticed that equations (number 7, 8 in table 1) ignored the soil factor while in equation number 9 the wetted perimeter is not taken into considerations. Despite that, these three equations (7,8, and 9 in table 1) were applied by many authors in Egypt and proved an acceptable compatibly with the Egyptian conditions.

3. CHARACTERISTICS OF THE STUDY AREA

3.1) Site and location

The current research focuses on the El-Sont branch canal and its off-takings as a representative canal for the Assuit countryside in Middle Egypt. The majority of its network is involved in a national canal lining and rehabilitation project. It begins at km 157 on the right bank of the Eastern Nag-Hamadi main canal in the East of Nile and extends approximately 40 kilometers to the north. It serves a total area of about 34,040 acres, divided between Abnoub (23,550 acres) and Sahel-Seleem (10,490 acres). Both are part of the Assiut Governorate's official irrigation engineering administration [21]. The total length of the off-taking canals is about 149.16 km.

3.2) Soil and ground nature

Soil samples were collected along the canal's path to determine its characteristics. Sampling occurs every five kilometers (for the main canal at km 2,7, 12,17, 23,28,33, 38) and one sample for every off-taking canal, from the canal bed and the side slopes and at various depths. Following sieve analysis, the soil samples were classified according to the American Association of State Highway and Transportation Officials (AASHTO) [22]. Most of them were A6 soil with a G.I. <12. Also, the different parameters and coefficients used in the empirical equations pertaining to the study were determined.

3.3) Weather and humidity

The study area is characterized as arid climate. The elevation of agricultural land is at 48 m above the mean sea water level. Using the meteorological data of the study area according to the recorded sheets of Arab-Alawamer official meteorological station, the maximum temperature reaches 40.7 ◦C and the minimum is about 22.4 ◦C. The maximum humidity is 63.2 % and the minimum is 36.5 % [14].

3.4) The Used Irrigation systems

The irrigation systems used in the study area is the traditional irrigation system. The network is divided into three irrigation rotations (five days' work & ten days off). The first irrigation rotation (A) begins at the head and ends at km 7.58. The second (B) stretches from km 7.58 to km 15.94. The third one (C) stretches from km 15.94 to the canal's terminus [21]. The constructed Fig. 1 depicts the served area and the length of each irrigation rotation.

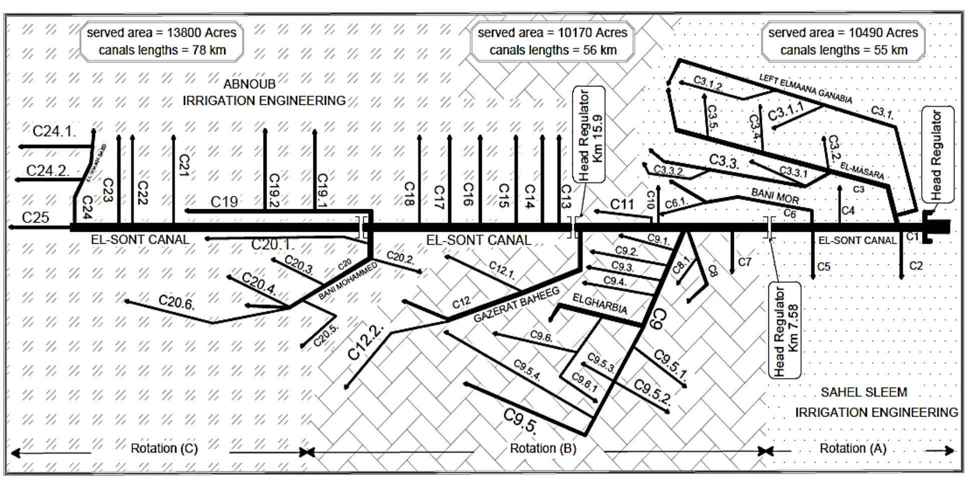

Fig. 1: El-Sont branch canal and its off-takings (irrigation rotations, served area and length).

3.5) Total given discharge and distributing canals network

Twenty-four off-taking canals branch directly from the El-Sont branch canal. The total network consists of 58 off-taking canals. The geometrical dimensions of the designed water sections of the total network are illustrated in appendix A [21] and [23]. Also, the average calculated discharge Q_{cal}. for the existing water sections is given using Manning equation.

4. METHODOLOGY AND DATA USED

In the study area, it was noticed that there are major distortions in the water sections, side collapses and the existent dimensions are different from that given in the design sheets so, the present study proceeds two ways for calculations of seepage as following:

- The first is using the dimensions of the design water sections that given in the design sheets (see Appendix A).
- The second is using the field measured dimensions from the existing water sections.

5. Estimating the seeped water

Hungarian equation [20] gives a very high and unacceptable values in our case study area, while using equations 1 through 8 (given in table 1), gave an acceptable and reasonable results for the quantities of seeped water from El-Sont branch canal, and its off-takings.

5.1) Calculations Using the Dimensions Given in the Design Sheets

Table 2 summarizes the obtained seeped water using the dimensions given in the design sheets, for each irrigation rotation in addition to the total seepage value for the entire network.

Table 2: Seepage losses for El-Sont branch canal and its off-takings during the irrigation rotations using designed dimensions

No.	Equation	Unit	El-Sont branch canal				Off-takings canals				Total Network
			Rotation (A)	Rotation (B)	Rotation (C)	Total	Rotation (A)	Rotation (B)	Rotation (C)	Total	
1	Molesworth & Yennidunia [15]	m^3/s	0.3389	0.6903	1.3352	2.3644	0.3939	0.3587	0.3635	1.1161	3.4804
		m^3/day	29279	59645	115357	204281	34031	30991	31403	96425	300706
		$Mm^3/year$	3.56	7.26	14.04	24.86	4.14	3.77	3.82	11.73	36.59
2	Molesworth &Yenni dunia [11]	m^3/s	0.3717	0.7080	1.4860	2.5657	0.4379	0.3378	0.4614	1.2371	3.8027
		m^3/day	32115	61171	128386	221672	37838	29184	39862	106884	328557
		$Mm^3/year$	3.91	7.44	15.62	26.97	4.60	3.55	4.85	13	39.97
3	Mortiz [17]	m^3/s	0.2313	0.4770	0.9993	1.7076	0.4927	0.4607	0.4737	1.4271	3.1347
		m^3/day	19986	41217	86337	147540	42573	39803	40924	123300	270840
		$Mm^3/year$	2.43	5.01	10.50	17.94	5.18	4.84	4.98	15	32.95
4	Davis & Wilson [18]	m^3/s	0.3767	0.7707	1.5311	2.6785	0.5451	0.5034	0.5096	1.5581	4.2366
		m^3/day	32545	66590	132291	231426	47093	43492	44031	134616	366043
		$Mm^3/year$	3.96	8.10	16.10	28.16	5.73	5.29	5.36	16.38	44.54
5	Ingham [19]	m^3/s	0.2161	0.4421	0.8645	1.5227	0.2837	0.2563	0.2545	0.7945	2.3173
		m^3/day	18671	38201	74697	131569	24508	22147	21990	68645	200213
		$Mm^3/year$	2.27	4.65	9.09	16.01	2.98	2.69	2.68	8.35	24.36
6	Indian [2]	m^3/s	0.4646	0.9506	1.7813	3.1965	0.4648	0.3904	0.3632	1.2184	4.4149
		m^3/day	40141	82130	153902	276173	40161	33734	31382	105277	381449
		$Mm^3/year$	4.88	9.99	18.72	33.59	4.89	4.10	3.82	12.81	46.40
7	Pakistani [2]	m^3/s	0.3819	0.7759	1.5641	2.7219	0.5683	0.5283	0.5651	1.6617	4.3836
		m^3/day	32997	67036	135139	235172	49104	45644	48827	143575	378747
		$Mm^3/year$	4.01	8.16	16.44	28.61	5.97	5.55	5.94	17.46	46.08
8	Nazir Ahmed [1]	m^3/s	0.4909	0.9570	1.8986	3.3465	0.5032	0.3652	0.4554	1.3238	4.6702
		m^3/day	42413	82683	164038	289134	43473	31556	39342	114371	403505
		$Mm^3/year$	5.16	10.06	19.96	35.18	5.29	3.84	4.79	13.92	49.09
Average		m^3/s	0.3590	0.7215	1.4325	2.513	2.513	0.4001	0.4308	1.2921	3.8051
		m^3/day	31018	62334	123768	217120	217120	34569	37220	111637	328757
		$Mm^3/year$	3.77	7.58	15.06	26.41	26.41	4.21	4.53	13.59	40.00

From the above table 2, the Indian [2], Davis & Wilson [18], Nazir Ahmed [1], and Pakistani [2] equations give close results of expected seepage values. These obtained values are the highest compared to results of other equations. Also, moderate seepage amounts are given by Molesworth

& Yennidunia [15], Mortiz [17], and Molesworth &Yenni dunia [11] equations. On the other side, seepage results obtained from Ingham equation [19] is the lowest.

5.2) Calculations Using the Existing Dimensions Measured in the Field

Table 3 shows the obtained seeped water using the existing water sections dimensions measured in the field. For accurate calculations all the studied network (El-Sont branch canal and its off-takings) were divided into reaches 300 m each, and the existing cross-sections dimensions were recorded and used in the calculations.

Table 3: Seepage losses for El-Sont branch canal and its off-takings during the irrigation rotations using existing dimensions

No.	Equation	Unit	El-Sont branch canal				Off-takings canals				Total Network
			Rotation (A)	Rotation (B)	Rotation (C)	Total	Rotation (A)	Rotation (B)	Rotation (C)	Total	
1	Molesworth& Yennidunia [15]	m^3/s	0.3403	0.5997	1.3073	2.2473	0.4689	0.3479	0.3191	1.1359	3.3831
		m^3/day	29398	51813	112949	194160	40514	30058	27568	98140	292300
		$Mm^3/year$	3.58	6.30	13.74	23.62	4.93	3.66	3.35	11.94	35.56
2	Molesworth &Yennidunia [11]	m^3/s	0.5921	0.6103	0.6477	1.8501	0.2463	0.4744	0.4459	1.1666	3.0169
		m^3/day	51161	52733	55965	159859	21283	40990	38526	100799	260659
		$Mm^3/year$	6.22	6.42	6.81	19.45	2.59	4.99	4.69	12.27	31.71
3	Mortiz [17]	m^3/s	0.2139	0.4079	0.9667	1.5885	0.5356	0.4252	0.4128	1.3736	2.9621
		m^3/day	18481	35243	83522	137246	46280	36738	35664	118682	255927
		$Mm^3/year$	2.25	4.29	10.16	16.7	5.63	4.47	4.34	14.44	31.14
4	Davis & Wilson [18]	m^3/s	0.4498	0.7543	1.5954	2.7995	0.6707	0.4934	0.4553	1.6194	4.4189
		m^3/day	38860	65175	137839	241874	57950	42628	39340	139918	381791
		$Mm^3/year$	4.73	7.93	16.77	29.43	7.05	5.19	4.79	17.03	46.45
5	Ingham [19]	m^3/s	0.2596	0.4239	0.9058	1.5893	0.3424	0.2413	0.2152	0.7989	2.3882
		m^3/day	22432	36626	78261	137319	29583	20851	18592	69026	206345
		$Mm^3/year$	2.73	4.46	9.52	16.71	3.60	2.54	2.26	8.4	25.11
6	Indian [2]	m^3/s	0.5688	0.8635	1.9069	3.3392	0.5265	0.3332	0.2641	1.1238	4.4629
		m^3/day	49146	74606	164752	288504	45491	28789	22816	97096	385599
		$Mm^3/year$	5.98	9.08	20.04	35.1	5.53	3.50	2.78	11.81	46.91
7	Pakistani [2]	m^3/s	0.4503	0.7064	1.1716	2.3283	0.3257	0.4504	0.4612	1.2373	3.5655
		m^3/day	38902	61033	101224	201159	28141	38911	39849	106901	308058
		$Mm^3/year$	4.73	7.43	12.32	24.48	3.42	4.73	4.85	13	37.48
8	Nazir Ahmed [1]	m^3/s	0.3584	0.6647	1.6370	2.6601	0.4898	0.3451	0.2963	1.1312	3.7912
		m^3/day	30964	57427	141434	229825	42323	29817	25596	97736	327561
		$Mm^3/year$	3.77	6.99	17.21	27.97	5.15	3.63	3.11	11.89	39.85
Average		m^3/s	0.4042	0.6288	1.2673	2.3003	0.4507	0.3889	0.3587	1.1983	3.4986
		m^3/day	34918	54332	109493	198743	38946	33598	30994	103538	302280
		$Mm^3/year$	4.25	6.61	13.32	24.18	4.74	4.09	3.77	12.6	36.78

From table 3 it is clear that, results obtained using the Indian [2], Davis & Wilson [18], and Nazir Ahmed [1] equations were the highest among the used equations, while results obtained using Molesworth & Yennidunia [15] equation, and Pakistani equation [2] gave moderate amounts of seeped water. At the same time, Mortiz [17], Molesworth & Yennidunia [11], and Ingham [19] equations gave the lowest values of the expected seeped water.

6. RESULTS AND DISCUSSION

According to table 2, and table 3 all equations, gave reasonable seepage values. On the other hand, the Ingham equation [19], proved a minimal value with acceptable results comparing those obtained from other equations. Maximum seepage values from El-Sont branch Canal's occur during the irrigation rotation (C), while the minimum seepage values occur during the irrigation rotation (A).

For the off-takings canals, the maximum seepage values occur during the irrigation rotation (A), whereas minimal seepage values occur during the irrigation rotation (C).

So, the analysis and discussion of the results will be divided as follows:

- Estimation of seepage losses from the El-Sont branch canal.
- Estimation of seepage losses from the off-takings canals.
- Estimation of seepage losses from the entire network.
- Ratio of the lost water through the off-takings canals to the lost water through the El-sont branch canal.

6.1) Estimation of seepage losses from the El-Sont branch canal.

Fig. 2 shows the results obtained using different seepage equations in (Mm^3/year) for the designed and existing dimensions of the El-Sont branch canal. From which the maximum amount of seepage for the designed dimensions is obtained using Nazir Ahmed's equation [1], and equals 35.2 Mm^3/year, after this, values of the Indian equation [2] which equals 33.6 Mm^3/year. While the smallest amount of seepage is obtained using Ingham's equation [19] which reaches about 16 Mm3/year, and that result was very close to Mortiz equation [17] results.

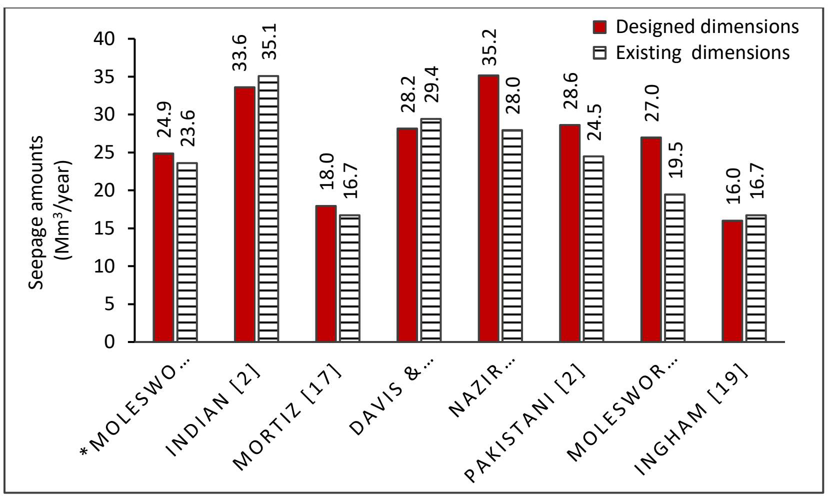

Fig. 2 Comparison between results of deferent seepage equation for the designed and the existing water sections of the El-Sont branch canal.

For the existing dimensions of the El-Sont branch canal, Indian equation [2] gives the maximum value of seepage which equals 35.1 Mm^3/year, then the Davis & Wilson equation [18] gives 29.4 Mm^3/year. While Ingham equation [19] gives the minimum value of seepage, which is 16.7 Mm^3/year. The average seepage value using all equations is 24.2 Mm^3/year which represents about 65.8% of the entire network seepage. In addition, the seepage values obtained using the designed dimensions are higher than those obtained using the existing dimensions except for the Indian [2], Davis & Wilson [18], and Ingham [19] equations. These three equations are highly affected with the distortion in the existing water sections.

6.2) Estimation of seepage losses from the off-takings canals.

Fig. 3 shows the various seepage values for the El-sont off-takings canals in (Mm3/year) based on seepage equations for the designed and existing dimensions. Pakistani equation [2] gives the maximum value of seepage of 17.5 Mm3/year for the designed dimensions, while for existing canals dimensions, the maximum value of seepage is given by Davis & Wilson equation [18] of about 17 Mm3/year. Whereas the minimum seeped water is given by Ingham equation [19] of about 8.4 Mm^3/year for both the designed and existing canals dimensions. The average seepage value calculated using all equations was 12.6 Mm^3/year, accounting for 34.5 percent of total seepage. Also, it reaches half of the El-Sont branch canal losses.

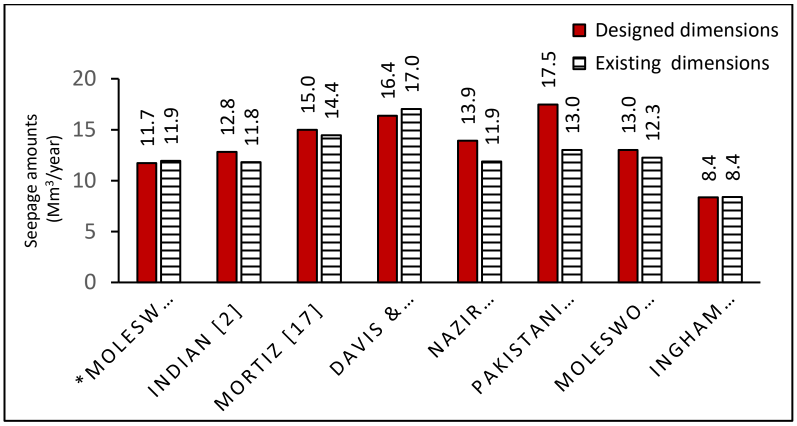

Fig. 3 Comparison between results of deferent seepage equation for the designed and the existing water sections for the off-takings canals.

6.3) Estimation of seepage losses from the entire network.

Fig. 4 shows the entire network results of seepage equations using the designed and existing dimensions. Nazir Ahmed's equation [1] gives the highest amount of seepage for the whole network's designed dimensions, which is 49.1 Mm^3/year, then the Indian equation [2] gives about 46.4 Mm^3/year. While, for the existing dimensions, the Indian equation [2] gives the greatest amount of seepage with 46.9 Mm3/s, then the Davis & Wilson equation [18] of about 46.5 Mm^3/year. On the other hand, Ingham equation [19] gives the lowest value of seepage which are 24.3 and 25.1 Mm^3/year for the designed and existing dimensions, respectively. These values represent about 10.6% and 11% of the total discharge. Also, the seepage values by Indian [2], Davis & Wilson [18] and Ingham [19] equations for the existing dimensions are higher than that using designed dimensions. That is because of the high distortion of water sections or high discharge values that are given to ensure reaching of irrigation water to the canals ends. Also, the big, wetted perimeter of the El-Sont branch canal.

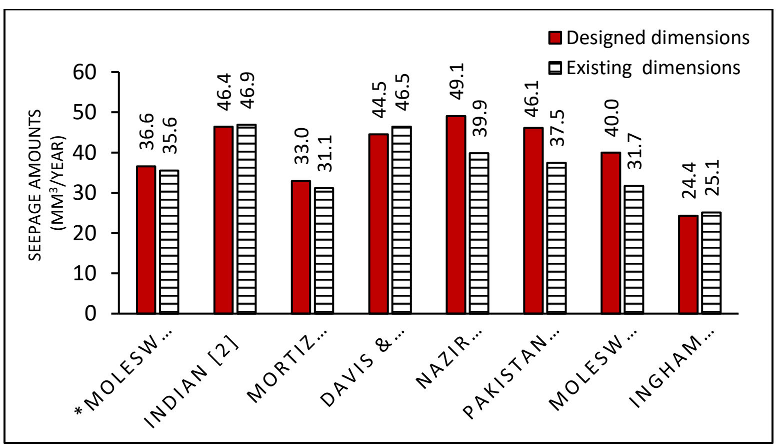

Fig. 4: Comparison between results of deferent seepage equations for the designed and the existing water sections for the entire network.

Also, it is seen that seepage amounts that obtained using Molesworth & Yennidunia [15], Indian [2], Davis & Wilson [18] and Ingham [19] Equations are very close for the designed and the existing dimensions. On contrary there is a big difference in results that obtained using Nazir Ahmed [1], Pakistani [2], Molesworth &Yennidunia [11] equations for the designed and the existing dimensions. This may be because of ignoring some involved parameters affecting the seepage in these equations such as soil type.

6.4) Ratio of the lost water through the off-takings canals to the lost water through the El-sont branch canal.

Fig. 5 depicts the El-Sont branch canal, and its off-takings canals share of total seepage losses for the designed dimensions during each irrigation rotation. The El-Sont branch canal's seepage losses account for around 43.8%, 64.3%, and 76.9% of the total losses during the irrigation rotations A, B, and C, respectively. While the off-takings canals seepage losses account 56.2%, 35.7%, and 23.1% of total losses during the same irrigation rotations, respectively. The existing water sections dimensions showed similar values, as seen from Fig. 6. The El-Sont branch canal's seepage losses account 47.3%, 61.8%, and 77.95% of the total losses during the irrigation rotations A, B, and C, respectively. Conversely, the canals' seepage losses account about 52.7%, 38.2%, and 22.1% of the total losses during the same irrigation rotations, respectively.

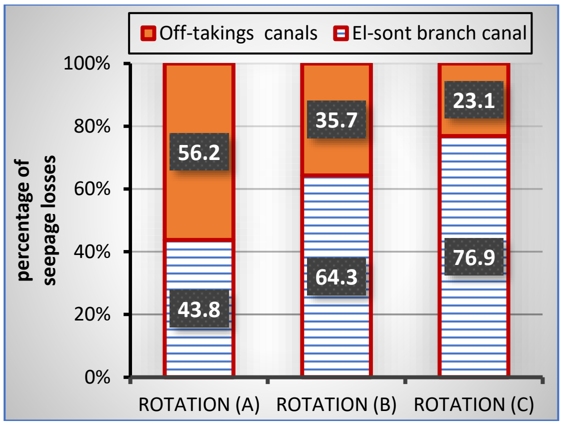

Fig. 5: Share of El-Sont branch canal and its off-takings losses from total seepage during irrigation rotations for the designed dimensions

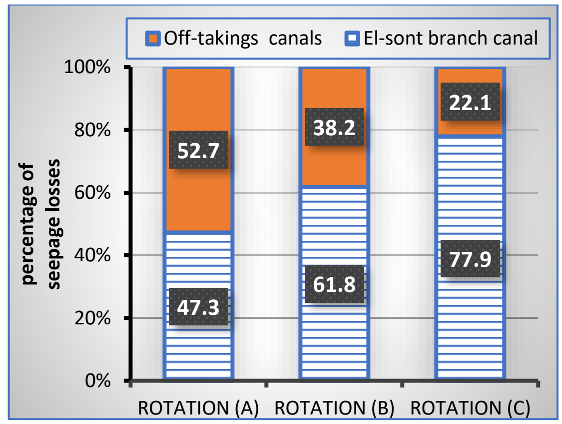

Fig. 6: Share of El-Sont branch canal and its off-takings losses from total seepage during irrigation rotations for the existing dimensions

For the designed dimensions, the average seepage value through El-Sont branch canal was 26.4 Mm^3/year representing 66% of the total seepage of the entire network because of two main reasons. The first, its large wide sections along its length of 40 kilometers. The second, its working time during the irrigation rotations A, B, and C. On the other hand, the average seepage value through off-takings canals was 13.6 Mm^3/year represents the remain value of losses with 34% of total seepage. This may be because of the smaller water sections of the off-takings canals, in addition to the separate applying of water discharges during each irrigation rotations. The same results is obtained using the existing dimensions with a slight difference.

According to Kraatz [11] seepage reductions reach about 60–80% by using hard surface lining such as concrete lining, but possible cracks or ill-constructed joints can cause considerable seepage losses. In our study case this type of lining is used so, the expected saved water amounts reach about 242103 m^3/day (supposing the lining will save about 60%). This value can be used for reclamation of about 4840 acres with using the modern irrigation systems. Such area reaches about 15% of the current total served area of the entire network.

CONCLUSIONS

After the above detailed description, discussion of the problem of seeped irrigation water through open channels cross-sections, and the available equations in the literature dealing with such problem the main technical points can be concluded:

- Among all the discussed available equations it can be said that the closest to the Egyptian case are equations of Molesworth & Yennidunia [15] , Molesworth & Yennidunia [11], Indian [2], Mortiz [17], Davis & Wilson [18], and Ingham [19] due to the big similarity between the involved parameters.

So, they can be used safely in calculating the expected seeped quantities of water through irrigation open channel networks with reasonable and accurate results.

- Using those equations in estimating the seeped quantities of irrigation water from the under study branch canal (El-Sont branch canal) and its off-takings, for both of calculating cases, by using the cross section dimensions given in the design sheets, and the field measured dimensions, the average seepage amount for the designed water dimensions was about 17.4% of the design discharge at the head of the branch canal, while for the existing dimensions it was about 22.8% of the given discharge. This is because of the big difference and great distortions between the designed and the existing in the field dimensions.
- The maximum calculated expected quantities of seeped water were given by Nazir Ahmed equation [1] with about 49 Mm^3/year (representing 21.5%), which is great amount. While the minimum expected seepage quantities were given by the Ingham equation [19] and equals 25 Mm^3/year (representing 11%), which still high amount of lost water.
- Such great quantities can be gained from the lost irrigation water through the under study El-Sont canal network (about 60% of the seeped water) can be used for reclamation of about 4840 acres (about 15% of the current total served area) using the modern irrigation systems.

NOTATIONS

a	Area of wetted perimeter	(M m^2)	L	Canal length	(m)
b	Bottom width	(m)	P	Wetted perimeter	(m)
$C_{1,2,3,4,5,6}$	Constant depends on soil parameters	-	Q	Discharge	(m^3/s)
d_a	Soil grain diameter	(m)	R	Hydraulic radius	(m)
H	Water depth	(m)	S	Seepage losses	(m^3/s)
i	Bed slope	(m/m)	v	Mean velocity	(m/s)
M	Million	(million)			

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Appendix *(A)* Table 4: Geometric dimension for the designed water sections of El-Sont branch canal and its off-takings and the calculated discharge

No	Canal Name	Section From Km	Section To Km	Bed Width	Side Slope	Water Depth (m)	Discharge (m^3/S) Q_D	Discharge (m^3/S) Q_{cal}
1	El-Sont (sahel sleem)	0	7.6	12	3:2	2.6	21.8	15.37
	El-Sont (abnoub)	7.6	15.94	11	3:2	2.6	17.62	13.73
		15.94	23.2	9	3:2	2.6	17.62	12.76
		23.2	26.4	8	3:2	2.35	15.33	9.54
		26.4	34.12	7	3:2	1.9	6.64	5.04
		34.12	39.9	5	3:2	1.4	5.76	4.11
2	Sothern Elnabary	0	3.2	1	1:1	1	0.35	0.98
3	Elmaasara	0	3.6	4	1:1	2.4	6.76	3.86
		3.6	6.98	3	1:1	1.75	3.98	3.86
		6.98	8.8	2	1:1	1.5	1.64	3.86
3.1	Left Elmaana Ganabia	0	5	3	1:1	1.85	2.7	1.92
		5	8.8	2	1:1	1.6	2.35	1.7
		8.8	10.45	1	1:1	1.15	0.82	0.25
3.1.1	Serage Banch	0	2	1	1:1	0.8	0.35	0.46
3.1.2	Elfaiama Branch	0	4	1	1:1	1	0.71	0.2
3.2	Amro Branch	0	2.4	1	1:1	0.9	0.27	0.42
3.3	Salebat Elmaasara Ganabia	0	1.3	4	1:1	1.4	1.52	1.02
		1.3	4.34	3	1:1	1.18	1.25	1.02
		4.34	5.4	2.5	1:1	1.1	0.85	0.8
		5.4	6.7	2	1:1	1	0.5	0.4
3.3.1	Elmanshia Branch	0	1.4	1	1:1	0.8	0.27	0.3
3.3.2	Elgamasea Branch	0	2.1	1	1:1	0.9	0.39	0.5
3.4	Elqasr Branch	0	1.14	1	1:1	0.9	0.27	0.85
3.5	Elquata Branch	0	1.36	1	1:1	0.75	0.26	0.28
4	Elghwaish Branch	0	1.3	1	1:1	0.75	0.21	0.15
5	Elnabari Alwasta	0	2.45	1	2:1	1	0.35	0.98
6	Bani Mor	4.5	5.2	3	1:1	1.5	2.04	1.23
		5.2	6.3	2	1:1	1	1	0.83
6.1	Quernaw Branch	0	1.42	2	1:1	0.75	0.27	0.2
7	Gazerat Bani Mor	0	1.6	1.5	3:2	1	0.4	0.64
8	Sahel Bani Mor	0	2.65	1.5	2:1	1	0.73	0.24
8.1	Elbaharwa	0	1.3	1	1:1	0.75	0.15	0.1
9	Elgharbia	0	2	4	3:2	1.75	4.62	4.12
		2	5.99	2.5	1:1	1	2.47	3.31
9.1	Hoshet Kom Aboshil	0	1.65	1	1:1	0.75	0.1	0.21
9.2	Ali Bek	0	2.1	1	1:1	0.9	0.35	0.29
9.3	Western Elnasara	0	3.75	2	1:1	1.65	0.85	0.21
9.4	Eastern Elnasara	0	3	2	1:1	1.7	0.85	0.61
9.5	Hablass	0	5	2	1:1	1.4	1	1.3

No	Canal Name	Section From Km	Section To Km	Bed Width (m)	Side Slope	Water Depth (m)	Discharge (m^3/S) Q_D	Discharge (m^3/S) Q_{cal}
9.5.1	Elakrad Branch	0	1.8	1	1:1	1	0.17	0.25
9.5.2	Bani Zeid Branch	0	2	1.5	1:1	0.85	0.22	0.14
9.5.3	Diab Branch	0	0.9	1	1:1	0.9	0.1	0.06
9.5.4	Hablas Elgadida	0	4.8	2	1:1	1.58	1.02	1.3
9.6	Hoshet Eltwabia	0	1.1	2	1:1	1.1	0.47	0.51
9.6.1	Eltwabia Southern Branch	0	2.25	2	1:1	1	0.27	0.21
10	Kom Abo Shail Branch	0	1	1	1:1	0.9	0.4	0.55
11	Right Southern Elsont Ganabiat	0	3	2	1:1	0.85	0.6	0
12	Baheege	0	2.4	4	3:2	1.5	2.71	1.45
		2.4	4.5	3	3:2	0.9	2.1	1.25
		4.5	6.3	2	3:2	0.75	0.4	0.55
12.1	Abo Amera	0	1.9	2	1:1	1.4	0.55	0.42
12.2	Elkhalifaa	0	1	1.5	1:1	1.2	0.35	0.56
13	Bani Rezah	0	2.6	2	1:1	1.1	0.42	0.27
14	Abnoub Branh	0	2	1	1:1	0.75	0.47	1
15	Elkadadeh Western Branch	0	2.2	1.5	1:1	1	0.93	0.31
16	Bani Ibrahem Western Branch	0	2.3	1	1:1	1.1	0.47	0.2
17	Elsawalem Southern Branch	0	2	1	1:1	0.95	0.6	0.22
18	Elrawateb Branch	0	1.25	1	1:1	0.85	0.38	0.2
19	Right Northern Elsont Ganabiat	0	3.3	4	3:2	1.5	3.25	1.44
		3.3	5.7	2	3:2	1.15	1.7	0.95
19.1	Elsihabia Branch	0	2.05	1	3:2	1.3	1	1.44
19.2	Asham Allah	0	1.6	1	3:2	1	0.5	0.64
20	Bani Mohamed	0	0.38	5	3:2	1.45	4.47	1.92
		0.38	3.7	4	3:2	1.3	3.34	1.41
		3.7	6.4	3	3:2	1.2	2.09	1.3
20.1	Left Northern Elsont Ganabiat	0	2.55	2	1:1	1	0.79	0.28
20.2	Elmarwna	0	1.1	1.5	1:1	1	0.23	0.3
20.3	Sahel Elaqab	0	1.3	1	3:2	1	0.31	0.16
20.4	Abo Diab Branch	0	1.7	1	1:1	1	0.63	0.21
20.5	Elmansora Western Branh	0	1	1	1:1	0.85	0.4	0.32
20.6	Sahel Bani Mohammed	0	4.5	2.5	3:2	0.9	1.04	0.74
21	Shaqequel	0	2	2.5	1:1	1.1	0.88	0.5
22	Elmaabda Sothern Branch	0	1.25	1	1:1	1	0.5	0.11
23	Elmaabda Northern Branch	0	2.8	2	1:1	1.25	1.5	0.52
24	Elshikh Saed Branh	0	1.2	3	1:1	1.2	1.88	1.34
24.1	Abo Meshel	0	1.1	1	1:1	0.75	0.28	0.28
24.2	Sahel Elmaabda	0	2.3	2	1:1	0.75	0.76	0.37
25	Emtedad Elsont	0	2	2	3:2	1.3	0.85	0.45