Article

Not peer-reviewed version

Field Study for the Assessment of the Water Losses Through the Open Irrigation Network Canals in Middle Egypt to the East Side of the River Nile

Mohamed Ashour , Mahmoud Sabry , Tarek S. Abu-Zaid *

Posted Date: 19 July 2023

doi: 10.20944/preprints202307.1349.v1

Keywords: Al Maanna Canal; seepage losses; evaporation losses; evapotranspiration losses

Article

Field Study for the Assessment of the Water Losses through the Open Irrigation Network Canals in Middle Egypt to the East Side of the River Nile

Mohamed A. Ashour [1], Mahmoud S. Abdel Nasser [2], Tarek S. Abu-Zaid [3,*]

1 Professor, Faculty of Eng., Assiut Univ., Egypt; mashour475275@yahoo.com
2 Ph.D. Researcher, Ministry of Water Resources and Irrigation; MahmoudSabry1977@yahoo.com
3 Associate Professor, Faculty of Eng., Assiut Univ., Egypt
* Correspondence: tareksayed1986@aun.edu.eg

Abstract: Egyptians face a significant challenge in meeting the growing population's water needs for agriculture and food production. To address this, policymakers and researchers have implemented the National Great Project for Lining and Rehabilitation of All Open Canals of the Irrigation Network to reduce irrigation water losses through seepage, evaporation, and evapotranspiration. The current field study evaluates water losses from the Al Maanna canal network in Assiut governorate, Middle Egypt, using empirical formulas and field ponding methods. The obtained results indicated that the Moleth-Worth formula is more compatible and gives results that are in good agreement with the field measurements carried out. The estimated seepage losses from the existing, distorted Al Maanna canal network using the Moleth-Worth formula and field ponding method were about 2.07 and 2.20 million m^3/month, respectively. Also, the calculated maximum evaporation and evapotranspiration losses were about 0.086 and 1.133 million m^3/month, respectively. Consequently, the total water losses might be about 3.42 million m^3/month, representing nearly 13.63% of the Al Maanna canal's total discharge. After completing the lining process, seepage losses from lined canals were determined to be only about 0.472 million m^3/month using the ponding method, while evaporation and evapotranspiration losses will be significantly decreased after canal rehabilitation. Hence, lining the Al Maanna canal network can decrease the total water losses by about 84%, which is sufficient to recommend and encourage the lining processes where the value of the gained quantities of water exceeds all the implementation expenses, in addition to other moral, cultural, and environmental gains.

Keywords: Al maanna canal; seepage losses; evaporation losses; evapotranspiration losses

---

1. Introduction

One of the biggest challenges facing Egyptians recently has been bridging the fast-widening gap between the limited quantity of water that is currently available and the huge quantity required to meet the needs of growing populations for agricultural and food production. That is why Egyptian policymakers as well as scientific researchers in Egypt have focused on finding radical solutions for such a problem and providing the largest possible amount of water through more than one tool at the same time. In addition to proceeding with extreme degrees of rationalization of water use in all sectors, the National Great Project for Lining and Rehabilitation of All Open Canals of the Irrigation Network all over the Egyptian Countryside was recently implemented, mainly to get rid of the main reason for irrigation water losses through seepage in permeable soil. That project not only preserves the seeped quantities of water but also minimizes the lost quantities that were lost through evaporation and evapotranspiration due to controlling the designed cross-sections of all irrigation water streams. Also, the project stops the increase in water sections, distortions, or swimming processes, as well as the growth of weeds and plants in irrigation water canals, which decreases the lost quantities of water. The Egyptian irrigation authorities expect to save about five thousand million cubic meters of water a year. The current field study aims to evaluate the water losses from the Al Maanna canal network in Assiut governorate as a representative case study for the Middle Egypt

 doi:10.20944/preprints202307.1349.v1

region. Also, the study contains an economic study of the saved costs after the lining process in the selected study area.

2. Literature Review

Water losses from earthen irrigation canals have several forms; the most important of these, which have a significant impact on water quantities, are seepage, evaporation, and evapotranspiration losses, which will be described in more detail in the following sections:

2.1. Seepage Losses

Seepage losses from earthen irrigation canals, which account for a significant portion of canal water losses, are determined by several factors, such as soil permeability, canal water depth, length of wetted perimeter, channel geometry, location of the groundwater table, velocity of flowing water, and so on. Worldwide, several researchers studied seepage losses from the earthen canals, as given in the following Table 1.

Table 1. Examples of previous studies on measuring of seepage losses from earthen canals.

Reference	The Study	Country	Major Findings
Mowafy (2001)	Seepage losses from Al Ismailia canal using empirical and analytical formulas.	Egypt	Minimum seepage losses occurred from reach 1 and maximum seepage losses occurred from reach 4
			The maximum seepage losses from reach 2 are 0.5753 (m^3/sec./km), and maximum seepage losses from reach 3 are 0.645 (m^3/sec./km)
Bakry, and Awad (1997)	Seepage losses from two main conveyance canals (Port-Said and Suez canals)	Egypt	Developed four equations based on the inflow-outflow method. The relations are applicable for canals having discharges ranging between 2 and 20 (m^3/sec.) $S = 9.533 \times 10^{-3} Q^{1.533}$ $S = 0.0369\, d^{3.969}$ $S = 1.146 \times 10^{-5} \times (P)^{3.053}$ $S = 1.696 \times 10^{-4} (P)^{1.931} (d)^{2.202}$ Where, S = Seepage losses (m^3/sec./km); Q = Discharge (m^3/sec.). d = Water depth (m); and P = wetted Perimeter (m)
Mahesh et al. (2013)	Seepage losses from canals and minors in Paithan Left Bank Canal and Lassina Left Bank Canal	Pakistan	Average seepage losses from lined and unlined canal were 0.836 and 7.063 (cumec/Mm^2), respectively
			Average seepage losses from lined and unlined minor canals were 3.01 and 4.93 (cumec/Mm^2), respectively
Adnan et al. (2015)	Seepage losses from Kabul River in Nowshera District	Afghanistan	Developed mathematical relationships between seepage and discharge *Linear solution:* $S = 0.00024Q + 0.298$ *Logarithmic solution:* $S = 0.294 \ln (Q) - 1.453$ *Power solution:* $S = 0.018Q^{0.494}$

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 19 July 2023 doi:10.20944/preprints202307.1349.v1

			Where, S = Seepage losses (m^3/sec./km); and Q = Discharge (m^3/sec.)
Eshetu and Alamirew (2018)	Seepage losses from irrigation canals in Tendaho Sugar Estate	Ethiopia	Average seepage losses were 0.55% per 100 m and 0.84% per 100 m from lined and unlined primary canals, respectively

Previous studies employed two basic strategies to quantify seepage losses from earthen canals: experimental formulas and field methods. A summary of these approaches is given below.

2.1.1. Experimental Formulas for Measuring Seepage Losses

The following Table 2 introduces a variety of experimental formulas that were used to quantify seepage losses from earthen canals.

Table 2. Experimental formulas for estimating seepage losses.

Formula Name	Seepage (S)	Factors	Units
Mortis [1]	$S = 0.2 * C * (\frac{Q}{V})^{0.50}$	Clay: C = 0.34. Sand: C = 2.2	American
Moleth - Worth and Yennidunia [1]	$S = C * L * P * R^{0.5}$	Clay: C = 0.0015. Sand: C = 0.003	SI
Indian [1]	$S = C * a * d$	C = (1.1: 1.8). a = Area of wetted perimeter (million ft²)	American
Pakistanian [1]	$S = 5 * Q^{0.0652} * P * L/10^6$	-----	American
Davis-Wilson [2]	$S = 0.45 * C * \frac{P * L}{4 * 10^6 + 3650 * \sqrt{V} * \sqrt[3]{d}}$	C = (1: 70) depends on bed material	SI
Inghum [3]	$S = 0.55 * 10^{-6} * C * P * L * d^{0.50}$	C = (1.5: 5.5)	SI
Offengenden [4]	$S = 10 * \alpha * Q^{1-\beta}$	(α-β) = (0.7-0.3), (1.9-0.4) and (3.4-0.5) for low, medium, and high permeable soil, respectively	SI
Nazeer Ahmed [5]	$S = \frac{0.04 * Q^{0.68}}{56.81}$	-----	SI

Sources: [1] Mowafy (2001); [2] Leigh (2014); [3] Dolatkhah et al. (2015); [4] Vivekanand et al. (2021); [5] Adnan et al. (2015). Notes in the above table: Q = Discharge; V = Water Velocity; L = Canal Length; R = Hydraulic Radius; d = Water Depth; P = Wetted Perimeter; SI = System International of Units.

2.1.2. The Field Ponding Method for Measuring of SEEPAGE losses

The field ponding method, which represents a direct method for measuring seepage losses from a considerable length of a canal, is based on restricting water in a certain reach of the canal and then measuring the water level twice: once after the restriction process and again after 24 hours. The reduction in the water level is considered a seepage loss (Leigh, 2014), as shown in Figure 1.

 doi:10.20944/preprints202307.1349.v1

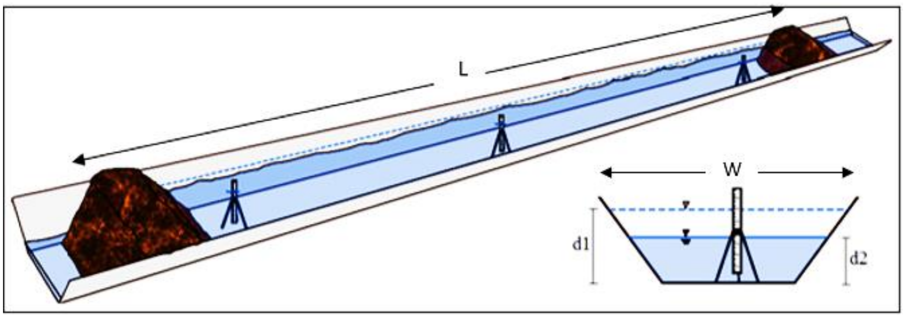

Figure 1. Ponding method for measuring of seepage losses.

Leigh (2014) proposed the following equation to calculate the seepage rates of ponding tests:

$$S = \frac{W * (d_1 - d_2) * L}{P * L} \quad (1)$$

where;
- S Average seepage losses from the ponded reach ($ft^3/ft^2/day$)
- W Average width of water surface in the ponded reach (ft)
- d_1 Water depth at the beginning of measurement in the ponded reach (ft)
- d_2 Water depth in the ponded reach after 24 hours (ft)
- P Average wetted perimeter in the ponded reach (ft)
- L Length of canal ponded reach (ft)

2.2. Evaporation Losses

Evaporation losses from the open canals, which depend mainly on the surface wind speed, are negligible in comparison to seepage losses. Suhua et al. (2016) used two methods to investigate evaporation losses from the middle reaches of the Heihe River in northern China: i) the aerodynamic method based on the Double-Deck Surface Air Layer (DSAL) model, and ii) the heat balance method. Results showed that cumulative evaporation losses estimated by the DSAL model were equal in order of magnitude to those estimated by the heat balance method. The evaporation losses were determined to be less than 1% of the total designed discharge. They also provided the following equation to predict a canal's evaporation losses:

$$R = (K_{p\times} Ep) * W * L \quad (2)$$

where;
- E_p Pan Evaporation(mm/day)
- W Width of water surface in the canal (m)
- L Length of canal(m)
- K_p Pan coefficient

2.3. Evapotranspiration Losses

Transpiration from the crops and evaporation from the soil make up the evapotranspiration in a cropped area. The evapotranspiration rate (crop water use) is determined by the crop type, growth stage, soil moisture content, and available energy to evaporate water (El-Enany et al. 2004). The reference crop evapotranspiration (ET_o) and an average crop coefficient (K_a) are used to calculate crop water use (ET_c) (Hanks, 1974), as follows:

$$ET_c = K_a * ET_o \quad (3)$$

The average crop coefficient (K_a) is estimated, as follows (Paul, et al., 1993):

$$K_a = (K_{cb} * K_s) + K_w \quad (4)$$

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 19 July 2023 doi:10.20944/preprints202307.1349.v1

where;	Ka	Average crop coefficient
	K_{Cb}	Basal crop coefficient
	K_w	Wet soil evaporation
	K_s	Water stress factor

On the other hand, Jensen et al. (1990) examined 20 methods to estimate ETo for arid and humid areas. For both areas, they found that the Penman-Monteith technique was the most accurate. The approach introduced by El-Enany et al. (2004) is used to calculate the water consumption (evapotranspiration losses) from a cultivated area as follows:

$$WC = \left(\frac{ET_O * K_a * A}{1000}\right) * \frac{4200}{86400} \quad (5)$$

where;	W_C	Water consumptive needed during a month (m^3/sec.)
	ET_o	Monthly reference crop evapotranspiration (mm/day)
	K_a	Monthly average crop coefficient
	A	Area cultivated (feddan)

3. Research Methodology

Assessment of water losses from the distorted irrigation networks in Assiut Governorate, as well as the positive impacts of the rehabilitation process, will be conducted through the following steps: i) Selection and description of a study area; ii) Surveying of soil types in the study area; iii) Collection of meteorological data that affects evaporation and evapotranspiration losses; iv) Collection of field data that affects seepage, evaporation, and evapotranspiration losses; v) Analyses and discussions of seepage, evaporation, and evapotranspiration losses (before and after rehabilitation); and vi) An economic study of the saved costs after the lining process in the selected study area.

3.1. Selection and Description of the Study Area

Al Maanna Canal is one of the main canals in Assiut Governorate. It takes its water from the Eastern Naga Hammady Canal and irrigates a cropped area of about 13500 feddan. The length of the Al Maanna Canal is roughly 32.8 km. This length is divided into five reaches, where the less ordered canals are branched on both sides, as shown in Figure 2. The branches have a total length of around 47 km (Abu-Zaid and Sabery, 2021). Table 3 summarizes the characteristics of the Al Maanna Canal and its branches.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 19 July 2023 doi:10.20944/preprints202307.1349.v1

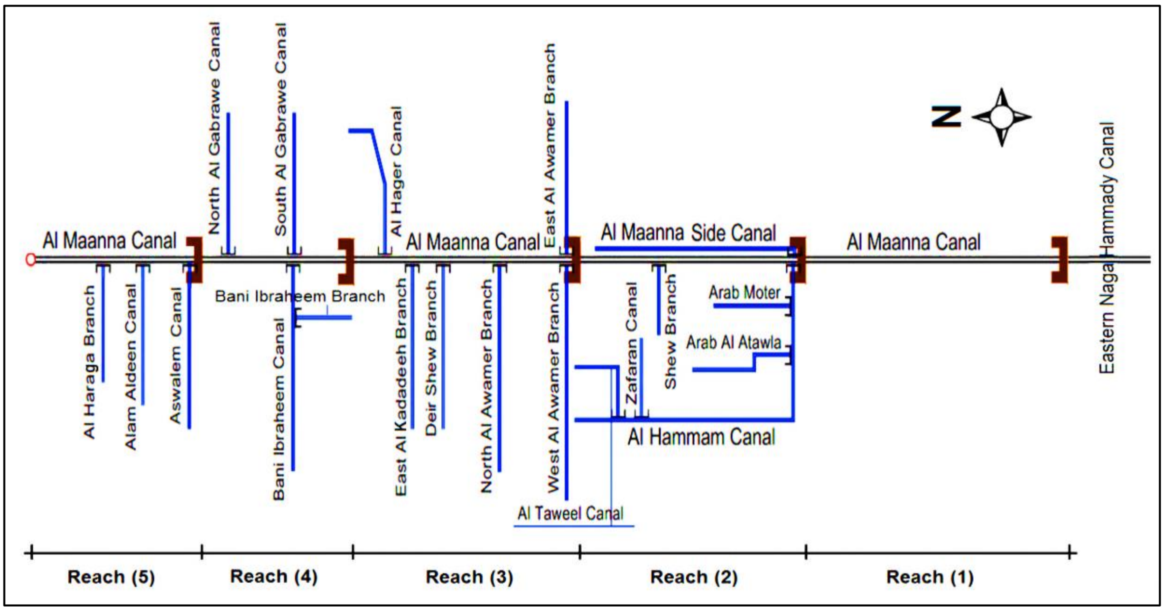

Figure 2. Schematic diagram of Al Maanna canal and its branches.

3.2. Surveying of Soil Types in the Study Area

It was required to take some samples along the canals' paths to determine the soil type, degree of permeability, and other physical properties. Every five kilometers along the main canal and one sample for every off-taking canal, soil samples were gathered at various depths beneath the canal bed and from the side slopes. All of these samples were subjected to sieve analysis, a liquid limit, a plastic limit, a plasticity index, and a group index test to estimate all of these parameters and coefficients.

Table 3. Characteristics of Al Maanna Canal and its branches (Abu-Zaid and Sabery, 2021).

Reaches of Al Maanna Canal							Branches of Al Maanna Canal				
				Area Served				Branches			
No.	Beginning	End	Length	Direct irrigation from Al Maanna Canal	Branches of Al Maanna Canal	Designed Discharge *	Location of Off-taking Branches	Secondary Branches	Length	Area Served	MeasuredDischarge *
	Km	Km	Km	Feddan	Feddan	m³/sec.	Km		Km	Feddan	m³/sec.
1	0.0000	10.450	10.450	zero	zero	19.34					
2	10.450	16.450	6.0000	1140	4850	21.79	10.500	Al Maanna Side	5.827	1000	2.05
							10.500	Al Hammam	9.000	3400	4.39
							1.0000	Arab Moter	2.000	600	1.45
							3.0000	Arab Al Atawla	2.400	500	1.65
							6.3000	Zafaran	2.300	400	1.34

							6.9400	Al Taweel	2.400	500	2.92
							12.500	Shew	2.300	450	1.26
3	16.450	23.060	6.6100	868	2680	14.65	16.500	East Al Awamer	0.670	400	0.04
							16.500	West Al Awamer	0.800	200	1.38
							17.800	North Al Awamer	1.400	780	1.93
							19.800	Deir Shew	1.000	400	0.50
							21.800	East Al Kadadeeh	1.000	400	0.74
							22.800	Al Hager	4.200	500	0.95
4	23.060	26.400	3.3400	zero	1700	8.23	23.800	South Al Gabrawe	2.200	500	2.01
							23.800	Bani Ibraheem	1.400	800	1.74
							0.250	Bani Ibraheem	1.350	400	1.45
							25.650	North Al Gabrawe	1.350	400	0.81
5	26.400	32.800	6.4000	562	1700	7.55	26.450	Aswalem	1.800	700	1.93
							27.600	Alam Aldeen	1.600	500	0.90
							28.350	Al Haraga	2.100	500	1.15
Total			**32.800**	**2570** **13500**	**10930**				**47.097**	**10930**	

* Designed discharge at the beginning of each reach and each branch.

3.3. Meteorological Data

Table 4 shows the available monthly meteorological data for the understudied region from the Arab Al-Awamer Weather Station (AAWS, 2020). These data include Air Temperature (T), Relative Humidity (RH), Pan Evaporation (Ep), Wind Speed, and Number of Sunny Hours per Day (SH/Day). These meteorological data were used to calculate evaporation and evapotranspiration losses from the Al Maanna canal and its branches, as analyzed and discussed further below.

Table 4. Meteorological data of the study area (AAWS, 2020).

Month	**Temperature (T)**			**RH**	**Ep**	**Wind Speed**	**SH/Day**
	Max.	**Min.**	**Avg.**				
		°C		**%**	**mm/day**	**km/hour**	**No.**
January	**18**	6.50	22.40	60.30	2.80	16.00	08.90
February	22.5	11.20	26.10	52.60	3.20	17.30	9.70
March	25	14.20	30.50	42.90	4.40	19.80	9.90
April	29	17.10	35.10	36.50	6.40	21.30	10.30
May	32	22.00	38.10	35.10	6.60	20.30	11.40
June	36	24.90	40.70	37.40	6.90	21.00	12.30
July	37	25.30	39.10	41.50	7.40	19.50	12.20
August	34.5	24.80	40.30	40.70	8.00	19.80	11.90
September	29	23.80	38.50	46.20	7.00	21.70	10.80
October	29	20.90	33.00	51.30	5.70	19.20	10.00

 doi:10.20944/preprints202307.1349.v1

November	27	13.20	27.00	54.70	5.00	15.20	09.40
December	22.5	9.00	23.20	63.20	3.10	16.80	09.00

3.4. Field Data

The gathered data from the study area of the Al Maanna canal and its branches were based on the required parameters to measure seepage, evaporation, and evapotranspiration losses from the network, as indicated below.

3.4.1. Field Parameters of Seepage Losses

In order to measure seepage losses, water was restricted in significant lengths of the Al Maanna canal and its branches using the field ponding method, as shown in photo (1); then the water level was measured twice, once after the restriction process and again after 24 hours, using the measuring device shown in photo (2). The ponding test seepage rates were calculated using the above-mentioned equation (1) proposed by Leigh (2014).

Photo (1) Ponding method for measuring of seepage losses.

Photo (2) Measuring device of ponding method.

3.4.2. Field Parameters of Evaporation Losses

Evaporation losses occur from both the designed (rehabilitated) and distorted cross sections of canals, depending on the top width of the exposed water surface. As shown in Figure 3, if the top water surface in the distorted cross section is bigger than the top water surface in the designed cross section, the evaporation rate from the distorted cross section of the canal will be positive (more than the evaporation rate from the designed cross section). However, if the top water surface in the distorted cross section is less than the top water surface in the designed (rehabilitated) cross section, as shown in Figure 4, the evaporation rate from the distorted cross section of the canal will be negative (less than the evaporation rate from the designed cross section). The distorted cross sections of Al Maanna canal and its branches were measured every 200 m along the canal's length and compared with the designed cross sections. The evaporation rates from the designed and distorted cross sections were estimated using the foregoing equation (2) provided by Suhua et al. (2016), associated with the meteorological data listed in the above Table 4.

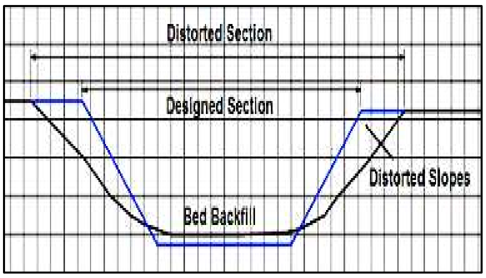

Figure 3. An example of positive.evaporation rate.

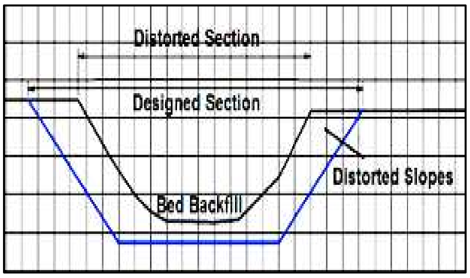

Figure 4. An example of negative evaporation rate.

3.4.3. Field Parameters of Evapotranspiration Losses

Most irrigation canals have extensive weed growth along their sides as well as siltation above the canals' beds. These conditions have an impact on the hydraulic characteristics of canals, such as the shape of the cross-section and its performance, the reduction of water velocity, and the limiting capacity of irrigation canals. As shown in Photo 3, growing weeds along the banks of the Al Maanna canal and its branches is a source of evapotranspiration losses from the network. The weeds' dimensions were estimated using a field measuring wheel, as shown in Photo 4. The areas of weeds along Al Maanna Canal and its branches were computed using these dimensions, as given in Table 5.

Photo (3) Example of weeds along Al Maanna canal network

Photo (4) Measuring wheel of weeds along canals

Table 5. Measured areas of weeds along Al Maanna canal and its branches.

Reaches of Al Maanna Canal		Branches of Al Maanna Canal	
Reach No.	**Area of Weeds (Feddan)**	**Branches / Secondary Branches**	**Area of Weeds (Feddan)**
Reach 1	37.17		
Reach 2	20.91	Al Maanna Side	6.91
		Al Hammam	10.21
		Arab Moter	3.80
		Arab Al Atawla	4.90
		Zafaran	6.66
		Al Taweel	2.48
		Shew	3.22
Reach 3	24.39	East Al Awamer	0.66
		West Al Awamer	0.92
		North Al Awamer	1.09
		Deir Shew	1.26
		East Al Kadadeeh	1.31
		Al Hager	4.70

Reach 4	11.62	South Al Gabrawe	1.77
		Bani Ibraheem	0.65
		Bani Ibraheem	2.12
		North Al Gabrawe	2.03
Reach 5	22.07	Aswalem	1.82
		Alam Aldeen	2.09
		Al Haraga	4.01
Total	**116.16**		**62.61**
	178.77 Feddan		

The above-mentioned equation (5), developed by El-Enany et al. (2004), was used to estimate evapotranspiration losses from the weeds along Al Maanna canal and its branches, based on the available meteorological data introduced in the above Table 4, in addition to the CROPWATER software model that was utilized to estimate the reference evapotranspiration (ET_o) from the weeds. It's worth noting that the CROPWATER software is based on the Penman-Monteith method (Allen et al. 1998).

3.5. Analyses and Discussions

The determination of seepage, evaporation, and evapotranspiration losses from the distorted and designed (rehabilitated) cross sections of the Al Maanna canal and its branches in Assiut governorate was achieved by using the literature review associated with the collected data for the study area. The following items have been separately analyzed to determine each water loss from the network:

3.5.1. Seepage Losses

As shown in the Figures 6 and 7, seepage losses from the distorted cross sections of Al Maanna canal and its branches were calculated using the field ponding method in addition to the experimental formulas presented in the foregoing Table 2.

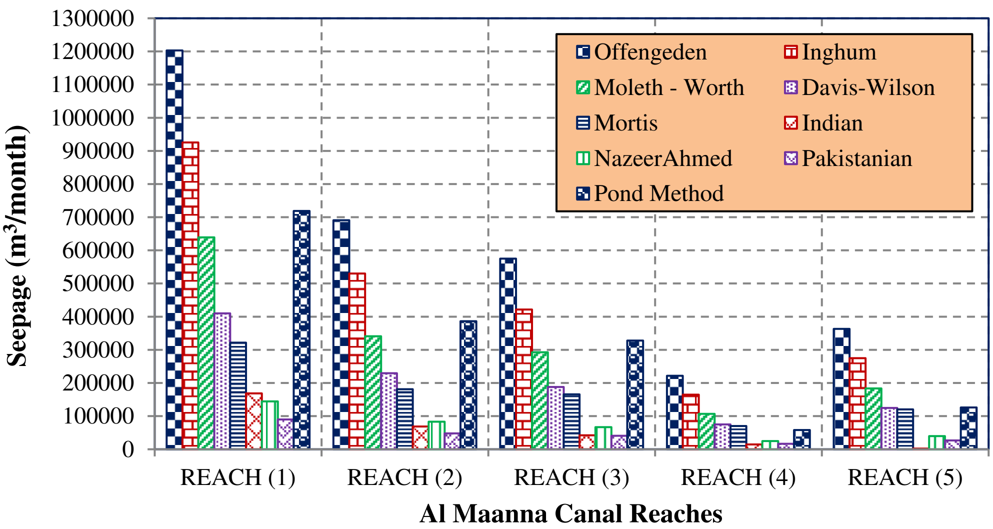

Figure 6. Seepage losses from the distorted sections of Al Maanna canal.

From Figure 6, it can be observed that the maximum seepage losses from the Al Maanna canal occurred from the first reach, using the Offengenden experimental formula. Using the Indian experimental formula, the fourth reach had the lowest seepage losses.

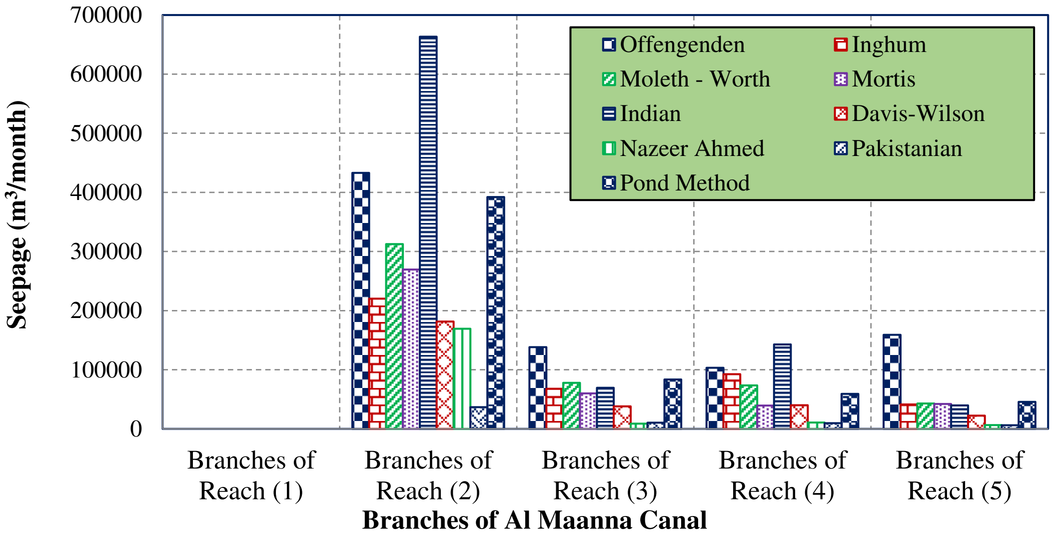

Figure 7. Seepage losses from the distorted sections of branches of Al Maanna canal.

From Figure 7, it can be noticed that the maximum seepage losses from the branches of the Al Maanna canal occurred from branches of the second reach using the Indian experimental formula. While, branches of the last reach caused the minimum seepage losses according to the Pakistani experimental formula. It should be noted that the first reach of the Al Maanna Canal has no branches.

The predictions of the experimental Moleth-Worth and Yennidunia formulas for measuring seepage losses are compatible with the field ponding method, as shown in Figures 6 and 7. Seepage losses from the distorted cross sections of the Al Maanna canal were estimated to be about 1,562,917 and 1,617,354 m^3/month by using the experimental Moleth-Worth formula and field ponding method, respectively. Seepage losses from the branches of the Al Maanna canal were estimated to be nearly 506,777 and 580,233 m^3/month by using the Moleth-Worth formula and ponding method, respectively.

After the lining and rehabilitation process of the Al Maanna canal and its branches, the field ponding method was conducted to estimate seepage losses from the lined cross sections, as illustrated in the following Figures 8 and 9.

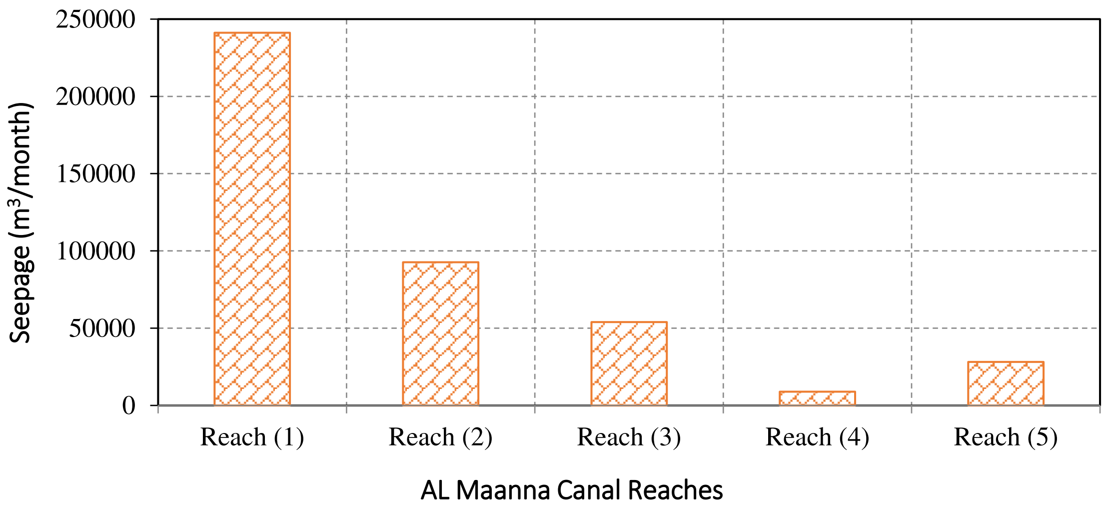

Figure 8. Seepage losses from the rehabilitated sections of Al Maanna canal.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 19 July 2023 doi:10.20944/preprints202307.1349.v1

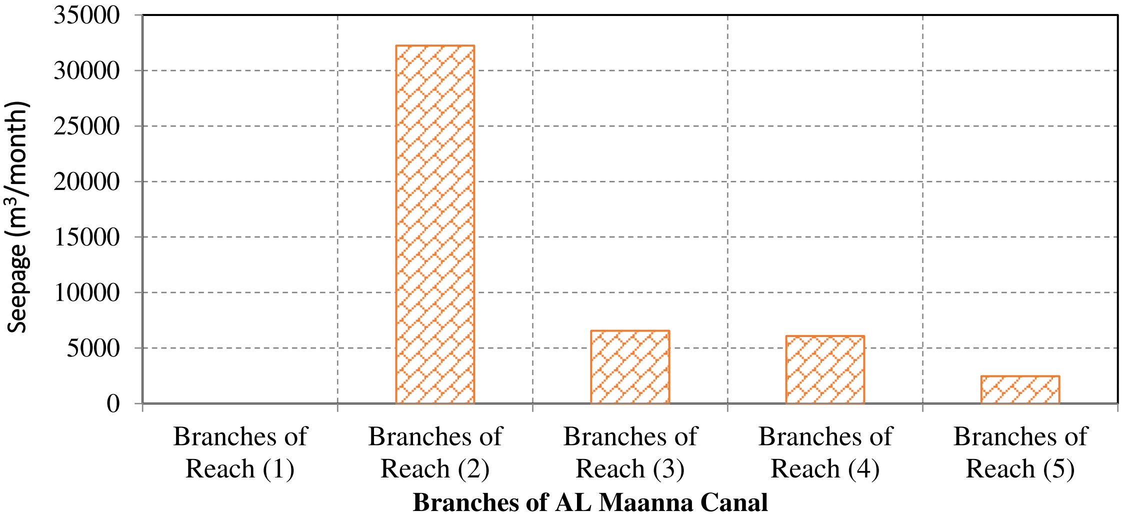

Figure 9. Seepage losses from the rehabilitated sections of branches of Al Maanna canal.

The highest seepage losses from the rehabilitated sections of Al Maanna Canal occurred in the first reach, as shown in Figure 8. The fourth-lined reach had the fewest seepage losses. Also, Figure 9 shows that lined branches in the second reach of the Al Maanna canal caused the most seepage losses. While the last reach's lined branches caused the least amount of seepage losses.

The calculated seepage losses from the distorted cross sections and the rehabilitated sections have a clear difference. After the lining and rehabilitation process of the Al Maanna canal network, the massive amounts of seepage losses were significantly reduced to about 472,255 m³/month, which represents nearly 21.48% of seepage losses before rehabilitation.

3.5.2. Evaporation Losses

Evaporation losses from Al Maanna canal and its branches obtained from the distorted and rehabilitated sections show a clear difference, as shown in Figures 10 and 11. Evaporation losses from the lined (designed) sections are lower than those from the distorted (earthen) sections due to the decreased top width of the exposed water surface in the rehabilitated sections.

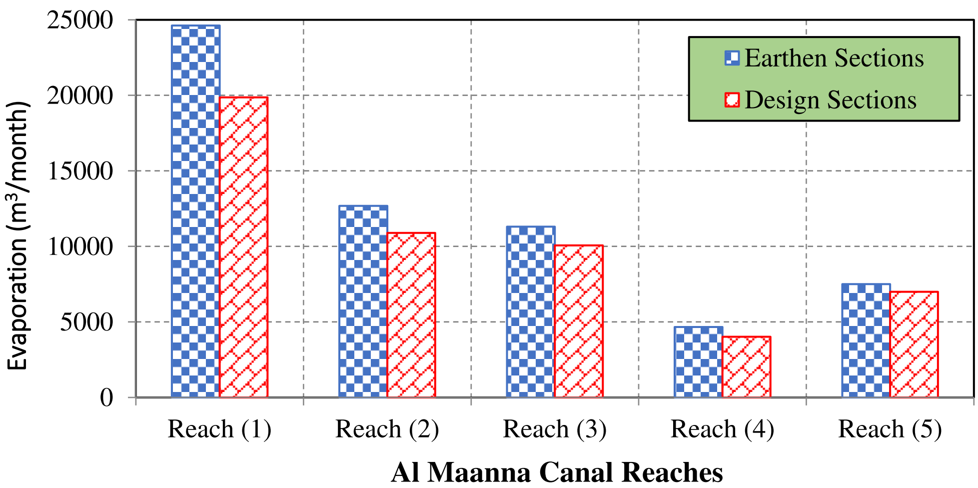

Figure 10. Evaporation losses from distorted and lined sections of Al Maanna Canal.

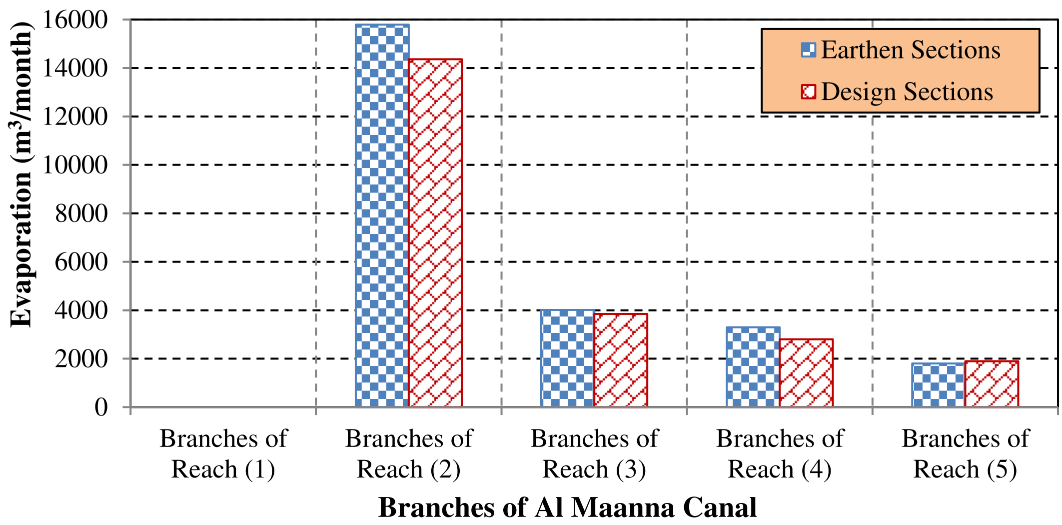

Figure 11. Evaporation losses from distorted and lined branches of Al Maanna canal.

Also, it should be noted that branches of the last reach have negative evaporation losses, as shown in Figure 11, which is considered an indication of decreasing the distorted cross sections compared to the lined sections in these branches. Evaporation losses from the distorted sections of the Al Maanna canal and its branches were estimated to be around 60,789 and 24,899 m^3/month, respectively. While, evaporation losses from the lined sections of Al Maanna canal and its branches were estimated to be about 51,856 and 22,905 m^3/month, respectively. As a result, evaporation losses can be reduced by roughly 10,926 m^3/month due to the rehabilitation of the Al Maanna canal network.

3.5.3. Evapotranspiration Losses

The first reach of the Al Maanna canal had the highest evapotranspiration rate from weeds, about 235,630 m^3/month. While the minimum evapotranspiration rate from weeds occurred in the fourth reach, at about 73,634 m^3/month, as presented in Figure 12.

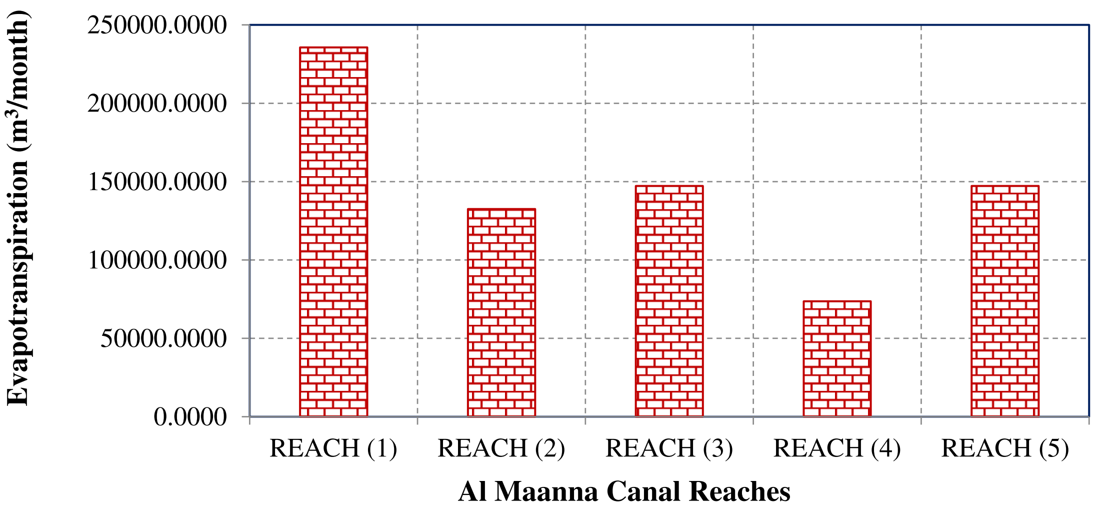

Figure 12. Evapotranspiration losses from weeds along Al Maanna canal.

These massive evapotranspiration losses caused by weeds along the banks of the Al Maanna canal and its branches will be ignored following the lining and rehabilitation process.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 19 July 2023 doi:10.20944/preprints202307.1349.v1

3.6. An Economic Study of the Lining Process in the Study Area

The traditional irrigation networks suffer from two main issues: (i) the growth of weeds along the banks of canals; and (ii) bed backfill. Weed removal occurred every three months, and canal dredging from bed backfill occurred once a year. For canals with a designed bed width of 10 m, weed removal costs approximately 5000 Egyptian pounds per km (LE/km), while bed dredging costs approximately 8 LE/m³ (MWRI, 2019). The total costs of bed dredging and weed removal from the distorted cross sections of Al Maanna canal and its branches are calculated and presented in the following constructed Tables 6 and 7.

Table 6. Costs of bed dredging and weeds' removal from Al Maanna canal cross sections.

Reach	Costs of Bed Dredging				Costs of Weeds' Removal			
Reach No.	Reach Length	Fill Area	Costs / m³	Total Costs	Designed Bed Width	Covered Length of Weeds	Costs / Km	Total Costs
	m	m²	L.E. *	L.E.	m	Km	L.E. *	L.E.
	{1}	{2}	{3}	{4} = {1}*{2}*{3}	{5}	{6}	{7}	{8} = {6}*{7}
Reach 1	10450	39.030	8.00	3262908	10.00	7.80595	5000	39029.75
Reach 2	6000	15.380		738240	7.50	4.87872		24393.60
Reach 3	6610	15.590		824399.2	6.00	5.73967		28698.35
Reach 4	3340	7.560		202003.2	4.00	4.06560		20328.00
Reach 5	6400	5.400		276480	3.00	6.17971		30898.55
Total		**82.960**		**5,304,030**		**28.66965**		**143,348.30**

* Costs in Egyptian Pounds determined by MWRI in the year 2019.

Table 7. Costs of bed dredging and weeds' removal from branches of Al Maanna canal.

Al Maanna Canal Branches	Length of Branch	Costs of Bed Dredging			Costs of Weeds' Removal		
		Fill Area	Costs / m³	Total Costs	Covered Length of Weeds	Costs / Km	Total Costs
Branches	**m**	m²	L.E. *	L.E.	Km	L.E. *	L.E.
Secondary Branches	{1}	{2}	{3}	{4} = {1}*{2}*{3}	{5}	{6}	{7} = {5}*{6}
Al Maanna Side	5827	0.852775	8.00	39752.96	5.277	5000	26385
Al Hammam	9000	1.834167		132060	9		45000
Arab Moter	2000	1.783		28528	1.9		9500
Arab Al Atawla	2400	0.8625		16560	2.400		12000
Zafaran	2300	1.493478		27480	2.295		11475
Al Taweel	2400	1.455		27936	2.400		12000
Shew	2300	1.453043		26735.99	2.299		11495
East Al Awamer	670	1.022687		5481.602	0.660		3300
West Al Awamer	800	1.5275		9776	0.800		4000
North Al Awamer	1400	2.315714		25936	1.400		7000
Deir Shew	1000	1.1244		8995.2	0.998		4990
East Al Kadadeeh	1000	1.392		11136	1.000		5000
Al Hager	4200	1.192143		40056	4.187		20935

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 19 July 2023 doi:10.20944/preprints202307.1349.v1

South Al Gabrawe	2200	1.319318		23220	2.197		10985
Bani Ibraheem	1400	1		11200	1.400		7000
Bani Ibraheem	1350	1.044074		11276	1.350		6750
North Al Gabrawe	1350	1.549259		16732	1.343		6715
Aswalem	1800	1.995556		28736.01	1.800		9000
Alam Aldeen	1600	1.860375		23812.8	1.463		7315
Al Haraga	2100	1.068571		17951.99	2.100		10500
Total		**28.14556**		**533,362.6**	**46.269**		**231,345**

* Costs in Egyptian Pounds determined by MWRI in the year 2019.

Weed removal occurs every three months, so the total annual cost of weed removal from Al Maanna Canal and its branches is approximately 1,498,773 LE per year.

According to the results of the above tables, the costs of bed dredging from the Al Maanna canal and its branches are approximately 5,304,030 and 533,363 Egyptian pounds, respectively. The costs of weed removal from Al Maanna Canal and its branches are approximately 573,393 and 925,380 Egyptian pounds per year. These costs can be saved after the lining and rehabilitation processes.

4. Conclusions

1. After studying the seepage, evaporation, and evapotranspiration losses from the distorted and lined sections of the Al Maanna canal and its branches, the following main conclusions can be drawn:
2. Using the most popular available equations for calculating the expected values of seeped water from the Al Maanna Canal, the obtained results were significantly different. This is due to the different conditions and properties of the soil in which the experiments were conducted, which produced each equation.
3. The results obtained using the Moleth-Worth formula were the most compatible with the measured seeped quantities of water by the field ponding method. The measured seeped quantities from Al-Manna canal were about 1.563 million m^3/month, while the calculated quantities using the Moleth-Worth equation were 1.617 million m^3/month. Also, the seepage losses from the Al Manna canal branches were approximately 0.506 and 0.580 million m^3/month, respectively, indicating an acceptable approximate difference.
4. The maximum calculated evaporation and evapotranspiration losses calculated from Al Maanna Canal were approximately 0.061 and 0.736 million m^3/month, respectively. While the maximum evaporation and evapotranspiration losses from the branches of the Al Maanna canal were calculated to be about 0.0249 and 0.397 million m^3/month, respectively.
5. The expected total seepage, evaporation, and evapotranspiration losses from the Al Maanna canal network might be about 3.42 million m3/month, which accounts for approximately 13.63% of the total discharge of the Al Manna Canal, which is so big.
6. After the lining process, the field ponding method was employed to estimate seepage losses from the Al Maanna canal and its branches, which were about 0.472 million m3/month. Also, evaporation losses after the rehabilitation process can be reduced to around 0.075 m^3 per month, while evapotranspiration losses will be neglected.
7. The lining of distorted sections of the Al Maanna canal and its branches can reduce water losses by approximately 84%, which is good and sufficient to recommend and encourage the lining processes, where the gained quantities of water are more valuable and important than the cost of implementation.
8. Saving not less than 5.84 Million L.E./year and 1.50 million L.E./year on the expenses of the regular periodic maintenance and weed removal costs for distorted Al Maanna canal sections and branches.

 doi:10.20944/preprints202307.1349.v1

Author Contributions: *Mahmoud S. Abdel Nasser* designed, collected the observed data, wrote the first draft, and edited the document. *Tarek S. Abu-Zaid* collected, processed, guided writing, and reviewed. *Mohamed A. Ashour* guided the writing and review. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The underlying research use data in this work were obtained officially from the Egyptian Ministry of Irrigation and Water Resources, while other used data was extracted from the results of previous studies in the field's scientific research literature.

Acknowledgments: The authors would like to mention that the second author involved in this paper has passed away before finishing it; the rest of the authors completed the paper and published it as a gift to his soul, praying for mercy and forgiveness for him.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Abu-Zaid, T. S., and Sabery, M., (2021), A New Approach for Water Allocation Scheduling in Irrigation Open Channels (Case Study: Al Maanna Main Canal, and Its Branches), Journal of Engineering Sciences, Assiut University, Faculty of Engineering, Vol. 49, No. 3, May, pp. 354-377. DOI: 10.21608/jesaun.2021.66660.1038
2. Adnan, T. A., Khan, K. S., and Laghari, M., (2015), Relationship between Seepage and Discharge for Kabul River in District Nowshera, Pakistan Journal of Agriculture, Agricultural Engineering and Veterinary Sciences, Vol. 31, No. 2, pp. 249-259. https://pjaaevs.sau.edu.pk/index.php/ojs/article/view/103
3. Allen, G. R., Pereira, L. S., Raes, D., and Smith, M., (1998), Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements, FAO Irrigation and Drainage, Paper No. 56, Rome, Italy. https://www.fao.org/3/x0490e/x0490e00.htm
4. Arab Al Awamer Weather Station (AAWS), (2020), Meteorological Data of Abnoub Cropped Area During the Period from 2014 to 2019 as Documented in the Arab Al Awamer Weather Station, Assiut, Egypt
5. Bakry, M. F., and Awad, A. A., (1997), Practical Estimation of Seepage Losses Along Earthen Canals in Egypt, Water Resources Management, Vol. 11, pp.197-206. https://doi.org/10.1023/A:1007921403857
6. Dolatkhah, S., Kazemiazar, F., Deljou, P., and Nourmand, B., (2015), Simulation of Seepage from Earthen Canals of Moghan Irrigation and Drainage Network Using Seep/w Model, Bulletin of Environment, Pharmacology and Life Sciences, Vol. 4, No. 1, pp. 430-435
7. El-Enany, M. A., El-Alfy, K. S., Sobeih, M. F., Armanious, S. D., and Gergis, E. S., (2004), Modification of the Improved Irrigation System in the Old Lands in Egypt, Mansoura Engineering Journal (M.E.J.), Vol. 29, No. 1, pp. 21-45
8. Eshetu, B. D., and Alamirew, T., (2018), Estimation of Seepage Loss in Irrigation Canals of Tendaho Sugar Estate, Ethiopia, Eshetu and Alamirew, Irrigation Drainage Sys Eng., Vol. 7, No. 3, pp. 2-5
9. Hanks, R. J., (1974), Model for Predicting Plant Yield as Influenced by Water Use, Agronomy Journal, Vol. 66, pp. 660-665
10. Jensen, M. E., Burman, R. D., and Allen, R. G., (1990), Evapotranspiration and Irrigation Water Requirements, Amer. Soc. Civil Eng., Man. and Rep. on Eng. Prac., No. 70, New York
11. Leigh, W. E., (2014), Evaluation of Methods for Predicting Seepage Loss Rates for the Hard Lined Irrigation Canal of the Lower Rio Grande Valley of Texas, M.SC. Thesis, University of Texas, A&M University, USA
12. Mahesh, M. K., Panke, R. A., and Hangargekar, P. A., (2013), Seepage Losses Through Canals & Minors, International Journal of Engineering Research & Technology (IJERT), Vol. 2, No. 11, pp. 1125-1134
13. Ministry of Water Resources and Irrigation (MWRI), (2019), Backfill and Weeds Removal Contract, Report, Egypt
14. Mowafy, H. M., (2001), Seepage Losses in Ismailia Canal, Sixth International Water Technology Conference (IWTC), Alexandria, Egypt, pp. 195-211
15. Paul, K. K., Gylan, L. D., and Nelton, O. S., (1993), Chapter 2: Irrigation Water Requirements, National Engineering Handbook, United States Department of Agriculture, Soil Conservation Service
16. Sabery, M., (2019), Hydraulic Performance Assessment for Improved Irrigation System, M.Sc. Thesis, Assiut University, Egypt

 doi:10.20944/preprints202307.1349.v1

17. Suhua, L., Weizhen, W., Makito, I., and Tetsuo, K., (2016), Estimating the Evaporation from Irrigation Canals in Northwestern China Using the Double-Deck Surface Air Layer Model, Advances Meteorology, Vol. 16, pp. 1-9
18. Vivekanand, I., Chandan, R., and Shashank, S. S., (2021), Determination of Canal Seepage Loss in Arrah Main Canal: A Case Study, Irrig. and drain, Vol. 3, No. 1, pp. 1-9