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Determination of Water Conveyance Loss in the Menemen Open Canal Irrigation Network

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Abstract: The aim of this research was to determine water conveyance loss in the open canal irrigation network that serves the irrigation areas on the right and left banks of the Menemen Plain, in the lower part of the Gediz Basin. The research was carried out in the main, secondary, and tertiary canals. Water conveyance loss in the canals was measured by the inflow-outflow method, while water velocity was determined using a current-meter. Statistical relationships between canal types, canal shapes, and seepage loss were also investigated. The water conveyance loss at the main canal level was between 0.5% and 1.3% (0.0071-0.0126 l s^{-1} m^{-2}) per 1 km in the left bank main canal, and between 0.6% and 8.6% (0.0024-0.0361 l s^{-1} m^{-2}) per 1 km in the right bank main canal. The average loss was 3.0% (0.0141 l s^{-1} m^{-2}). At the secondary canal level the average water conveyance loss for the trapezoidal canals on the left bank was 2.0% (0.0615 l s^{-1} m^{-2}) per 100 m and for the concrete flumes on the right bank it was 4.0% per 100 m. Average conveyance loss at the tertiary level on the left bank was 7.0% (0.0598 l s^{-1} m^{-2}) per 100 m for the trapezoidal canals and 5.1% per 100 m for the concrete flumes. For the concrete flumes on the right bank the figure was 6.5% per 100 m. Based on the statistical analysis, there was no significant difference for seepage loss between secondary and tertiary canal types ($\bar{X}_{secondary} = 18.600^a \pm 4.404$ and $\bar{X}_{tertiary} = 9.173^a \pm 3.199$), but there were statistically significant ($P < 0.05$) differences in seepage loss between the canal shapes (trapezoidal and concrete flume) ($\bar{X}_{trapezoidal} = 21.892^a \pm 3.664$ and $\bar{X}_{concrete\ flume} = 5.881^b \pm 4.025$). On the other hand, the interaction between canal type and canal shape was significant ($P < 0.05$). It was noted that the average seepage loss of the trapezoidal secondary canal was much higher than the average seepage loss of the trapezoidal tertiary canals. Moreover, the reduction in the average seepage loss of the concrete flume secondary canal was lower than the average seepage loss of the concrete flume tertiary canals. The results showed that overall water conveyance loss in open canals increased in comparison to the average values measured 30 years ago, and that water conveyance loss was higher than the average value set for both the open canal irrigation networks of Turkey and the accepted value of water conveyance loss for open canals. This revealed that, overall, maintenance and repair work on the conveyance canals were not sufficient.

Key Words: Conveyance loss, seepage, irrigation network, open canal, Menemen

Menemen Ovası Açık Kanal Sulama Şebekesinde Su İletim Kayıplarının Belirlenmesi

Özet: Bu çalışmada, Aşağı Gediz Havzası içerisindeki Menemen Ovasının sağ sahil ve sol sahil sulama alanlarına hizmet veren açık kanal sulama şebekesinde su iletim kayıplarının belirlenmesi amaçlanmıştır. Çalışma, ana, sekonder ve tersiyer kanal düzeyinde yürütülmüştür. Kanallarda iletim kayıpları giren-çıkan akım yöntemiyle, su akımları ise muline yardımıyla belirlenmiştir. Ayrıca, sızım kayıplarıyla kanal tipleri ve kanal şekilleri arasındaki istatistiksel ilişkiler araştırılmıştır. Ana kanal düzeyinde iletim kayıpları; sol ana kanal için 1 km'de % 0.5-1.3 (0.0071-0.0126 l s^{-1} m^{-2}) arasında, sağ ana kanal için 1 km'de % 0.6-8.6 (0.0024-0.0361 l s^{-1} m^{-2}) arasında, ortalama ise 1 km'de % 3.0 (0.0141 l s^{-1} m^{-2})'tür. Sekonder düzeyinde ortalama iletim kayıpları, sol sahildeki trapez kanallar için 100 m'de % 2.0 (0.0615 l s^{-1} m^{-2}), sağ sahildeki kanaletler için 100 m'sinde % 4.0'tür. Tersiyer düzeyindeki ortalama iletim kayıpları, sol sahildeki trapez kanallar için 100 m'de % 7.0 (0.0598 l s^{-1} m^{-2}) ve kanaletler için 100 m'sinde % 5.1, sağ sahildeki kanaletler için ise 100 m'sinde % 6.5 olarak bulunmuştur. İstatistiksel analizde; genel olarak sekonder ve tersiyer kanal tipleri arasında sızım kayıpları bakımından farklılık olmadığı ($\bar{X}_{sekonder} = 18.600^a \pm 4.404$ ve $\bar{X}_{tersiyer} = 9.173^a \pm 3.199$) saptanmıştır. Kanal şekilleri (tersiyer ve kanalet) arasında sızım kayıpları bakımından önemli ($P < 0.05$) farklılıklar ($\bar{X}_{trapez} = 21.892^a \pm 3.664$ ve $\bar{X}_{kanalet} = 5.881^b \pm 4.025$) belirlenmiştir. Bununla birlikte kanal tipi ile kanal şekli arasındaki interaksiyon etkisi önemli ($P < 0.05$) bulunmuştur. Ortalama sızım kayıplarının, trapez şeklindeki sekonder kanallardan tersiyer kanallara geçildiğinde oldukça azaldığı, buna karşın kanalet şeklindeki sekonder kanallardan tersiyer kanallara geçildiğinde ise çok az arttığı anlaşılmıştır. Bu sonuçlar, şebekenin tüm açık kanallarında su iletim kayıplarının 30 yıl önceki ortalama değerlere göre arttığını ve Türkiye'deki şebekeler için belirtilen ortalama değer ile açık kanallar için belirtilen iletim kaybı sınır değerlerinin üzerinde olduğunu göstermektedir. Bu durum ise, şebekedeki tüm iletim kanallarında bakım-onarım çalışmalarının yeterli olmadığını ortaya koymaktadır.

Anahtar Sözcükler: iletim kaybı, sızım, sulama şebekesi, açık kanal, Menemen

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Introduction

The total area of Turkey under agriculture is nearly 28.1 million hectares. Taking into account today's economic conditions and restrictions regarding soil features and topography, 13.5 million hectares of this area can be irrigated (Yıldırım, 1996). As of 2005, the agricultural area under irrigation was 4.87 million hectares; 94% of this area is irrigated with surface irrigation methods. However, the General Directorate of State Hydraulic Works (DSİ) has recently been building piped irrigation systems, the maintenance and repair expenses of which are lower, and which enable pressurized irrigation methods (DSİ, 2006). It is considered that water prodigality due to surplus seepage and operational loss, together with maintenance and repair expenses, which have been transferred to the water user associations (WUAs), are chief among the principal problems that are encountered in open canal irrigation systems (Çevik et al., 2000).

In Turkey, as in the rest of the world, a rising population and increasing industrialisation demand the active exploitation of water resources. In developing countries, 70%-80% of water is used in agriculture (Hamdy et al., 2000). Since agriculture is the major user, water loss during conveyance and distribution in irrigation networks is of great importance.

Water conveyance loss consists mainly of operation losses, evaporation, and seepage into the soil from the sloping surfaces and bed of the canal. The most important of these is seepage. Evaporation loss in irrigation networks is generally not taken into consideration (Xie et al., 1993; Çevik and Tekinel, 1995; Kanber, 1997; Ancid, 2000). Şener (1976) stated that seepage loss in the irrigation canals on the right and left banks of the Menemen Plain accounted for the major portion of water conveyance loss (98.37%). According to Reid et al. (1986), approximately 0.3% of the total stream is lost due to evaporation (Badenhorst et al., 2002).

The problems resulting from water conveyance loss due to seepage in canals are divided into 2 groups. The first is prodigality of water, which is obtained at a high cost and with difficulty from various sources. The second is the problem of drainage, salinity, and alkalinity, which result from a rising water table (Balaban, 1970).

Regarding irrigation networks in Turkey, it has been stated that seepage loss from concrete trapezoidal canals and concrete flumes with a semicircular or elliptical cross section has reached a serious level, but that maintenance work remains insufficient (Bekişoğlu, 1993).

Bekişoğlu (1993) stated that the water conveyance loss, which occurs in concrete canals in Turkey, varied between 0.0026 and 0.0754 $l\ s^{-1} m^{-2}$ (average 0.0321 $l\ s^{-1} m^{-2}$). The Bureau of Reclamation (1975) gave the standard of seepage for concrete canals as 0.00024 $l\ s^{-1} m^{-2}$ (Bekişoğlu, 1993). Kraatz (1977) stated that, if concrete canals were built properly and well maintained, seepage loss would occur below the value of 0.03 $m^3\ m^{-2}\ day^{-1}$ (about 0.0003 $l\ s^{-1}\ m^{-2}$). However, LWRRDC (2002) reported that, if concrete canals were built properly and well maintained, seepage loss would occur below the value of 0.0005 $m^3\ m^{-2}\ day^{-1}$ (about 0.00001 $l\ s^{-1}\ m^{-2}$). Regarding these values, it can be concluded that canal seepage loss in Turkey is at a critical level.

The principal causes of seepage loss in conveyance and distribution canals in irrigation networks in Turkey occur in concrete-lined canals (faulty construction, deformation of the concrete structures over time caused by land movement and the water table) and in flumes (cracking and open gaps where flumes join together) (Balaban, 1970; Şener, 1976; Bekişoğlu, 1993; Şanlı, 1996; Ünal et al., 1999).

The main repair and maintenance activities provided by the DSİ in open canal irrigation networks include the removal of sediment from irrigation and drainage canals, repairing the concrete of irrigation canals, and maintenance of service roads. In networks operated by DSİ, it carries out these activities, and in networks, which have been transferred to WUAs, DSİ supervises the operations (DSİ, 2003).

It has been stated that it is necessary to take some action to prevent seepage, such as changing broken concrete flumes, sealing joints between concrete flumes, and using mastic asphalt and shotcrete in the lining of canals (Bekişoğlu, 1993). According to Plusquellec (2006), the efficiency of rigid canal lining (concrete) may decline rapidly over time, especially when low construction standards and poor operation procedures are used. Geosynthetics (geomembranes and geotextiles) provide a long-term solution to the control of seepage loss.

In a study to develop technologies for canal linings at lower cost and with less seepage from canals in hard ground conditions, 4 different canal linings: i) concrete alone, ii) fluid-applied membrane, iii) exposed geomembrane, and iv) geomembrane with concrete cover were tested. According to the results of the tests, the fourth type of lining was found to be better than the others because of its durability (40-60 years), low maintenance costs (0.005 \$ ft^{-2} $year^{-1}$), high efficiency (95% seepage reduction), and cost/benefit ratio (3.5:3.7) (Swihart and Haynes, 2002).

In a study performed to determine an ideal mixture and type of cement for irrigation canal linings among the kinds of cement produced in Turkey, 4 kinds of cements (portland, puzzolanic, composite, and sulphate-resisting) were used. The amount of seepage that occurred in concrete canals built using each kind of cement was found to be considerably below both the average for Turkey (0.0321 $l\ s^{-1}\ m^{-2}$) and the seepage standard of the Bureau of Reclamation (0.00024 $l\ s^{-1}\ m^{-2}$) (Büyüktaş and Alagöz, 2004).

In Turkey, as in other countries, the efficient use of water resources is of vital importance in increasing agricultural productivity, and thus it is necessary to determine water conveyance loss in irrigation canals and to find economical solutions to reduce the loss to a minimum level (Şener et al., 1992). Furthermore, by increasing irrigation efficiency in this way, both economic and operational performance of the systems can be improved.

It has been stated that efficiency values given for large irrigation projects in Turkey are usually merely the average values in the literature, and that research into the actual values regarding efficiency is needed so that water resources can be used in an efficient and economical way (Çevik and Tekinel, 1995). In this regard, further research is needed to determine conveyance loss in open canals in order to determine the actual conveyance efficiency values in the irrigation network that serves the Menemen Plain.

The aim of this study was to determine the water conveyance loss of the open canal irrigation network of the Menemen Plain, in the lower part of the Gediz Basin. The measured conveyance losses were compared to each other and with other values of seepage criteria, and the adequacy of the system's maintenance work was investigated.

Materials and Method

Material

This study was carried out in the Menemen Plain irrigation network, which serves 22,865 hectares of land at the end of the lower Gediz Basin. The plain is largely alluvial. Annual average temperature is 17 ºC and annual average rainfall is 540 mm. The main crops are cotton and grapes, but also include citrus, cereals, and vegetables (KHGM, 1995; DSİ, 2000).

Water diverted from the Emiralem Regulator on the Gediz River to the Menemen Plain irrigation system is distributed through the right and the left bank irrigation networks (Figure 1). This system began operation along with the regulator in 1944, and at first consisted of the left bank canal network of partly soil- and partly concrete-lined trapezoid canals, which were later all lined with concrete at the end of the 1970s. The right bank canal network, whose secondary and tertiary canals are entirely concrete flumes, was opened in 1974. The network now consists of 77,711 m of main canals, 151,044 m of secondary canals, and 547,599 m of tertiary canals (DSİ, 2000). In the research area, a limited amount of renovation has been carried out, and together with land consolidation, which started in 1990, the length of the tertiary canals has been increased, mainly in the left bank irrigation network, and trapezoidal concrete canals, which had become deformed, have been turned into concrete flumes (Ünal Çalıskan and Ünal, 2005). Water management in the irrigation system is carried out by 31 irrigation groups and the Menemen Left Bank and Right Bank WUAs, which were founded in 1995. The money that the WUAs spend on maintenance and repair accounts for a small portion of their budgets. For instance, expenditure of the Menemen Left Bank WUA between the years 1998 and 2002 for maintenance and repair work amounted to 2.5%-13.7% of its budget (between \$13,000 and \$64,000 per year) (Aşık et al., 2004). The left main canal irrigation network still has infrastructure problems, which have economic, social, and environmental repercussions, and which adversely affect the performance of water distribution (Ünal et al., 1999, 2004a; Ünal et al., 2004b).

Method

In this study, an inflow-outflow method was used, which showed the loss occurring during water conveyance in the open canals without obstructing the

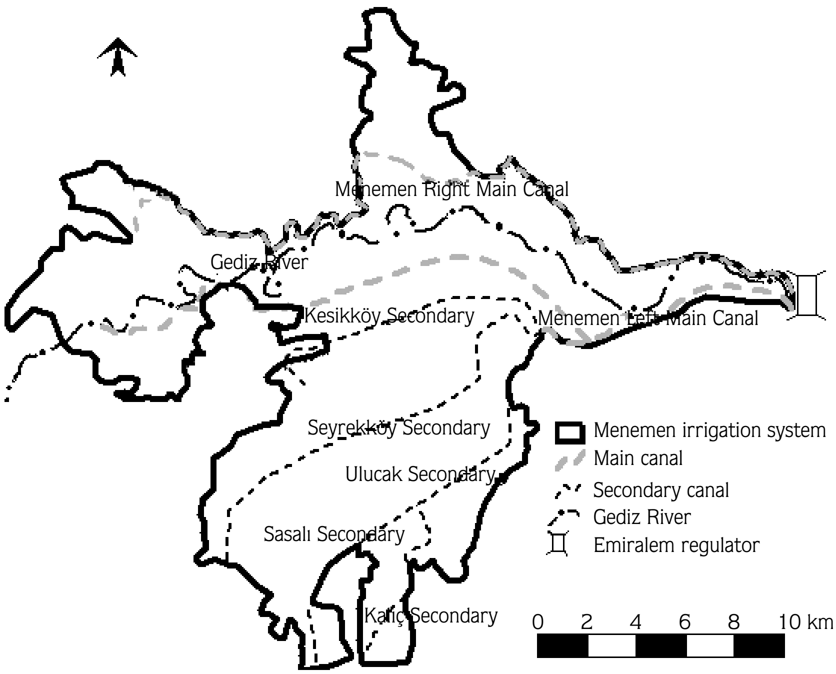

Figure 1. General plan of the Menemen irrigation network.

seasonal irrigation operation of the selected canals, but at the same time allowed sufficiently accurate measurements (NRCS, 1997; LWRRDC, 2002; Ancid, 2003). With this method, the following formula was used to calculate water conveyance loss in defined canal sections of sufficient length (Ancid, 2003):

$$S = Q_i - Q_o - E - D + I$$

where S is conveyance loss in the canal segment (l s^{-1}), Q_i is inflow to the segment (l s^{-1}), Q_o is outflow from the segment (l s^{-1}), E is evaporation (l s^{-1}), I is inflow to the segment from other sources (l s^{-1}), and D is water diverted from the segment (l s^{-1}).

Water conveyance loss in the canals was calculated 3 different ways: i) conveyance loss per unit of canal length (l s^{-1} km^{-1} and l s^{-1} 100 m^{-1}), ii) conveyance loss as a percentage of inflow (% per 1 km and % per 100 m), and iii) conveyance loss per unit of wet area of the trapezoid canals per unit of time (l s^{-1} m^{-2}) (Balaban, 1970; LWRRDC, 2002).

Flows at the beginning and end of segments of the main, secondary, and tertiary trapezoidal canals were calculated according to the velocity-area flow measurement method. The canal cross-section at the measurement points was first divided into subsections, and velocity values were measured for each subsection by the 2-point method, or, for shallow water with a depth < 0.5 m, the six-tenths method, using a propeller current meter calibrated by the DSİ Hydraulic Laboratory (Kanber, 1997; Bayazıt, 1999; USBR, 2001). Flow velocity at the measurement points was calculated in relation to the revolutions of an Ott-type current meter over a period of 60 s (Teker, 1985). Flow velocity was calculated using the following equation:

$$V = 0.2541\ n + 0.014$$

where 0.2541 is the coefficient of the propeller type and 0.014 is the coefficient of the friction of the propeller, both of which were found by calibration, n is the number of revolutions per second of the propeller, and V is the flow velocity of the water (m s^{-1}).

When using the 2-point method, the flow velocity was measured at 2 vertical points, 0.2 (20%) and 0.8 (80%) depths, respectively, from the top of the water surface. The flows at these 2 levels were then averaged to get a single measurement. Velocity should generally be larger at the 0.2 depths, but should not be larger than twice the velocity at the 0.8 depths. If the velocity at the 0.2 depths was not larger than the 0.8 depths or if it was twice as great as the 0.8 depths, then an additional reading was taken at the 0.6 depths. These 0.6 depths were averaged with the 0.8 and 0.2 means (Du Plessis, 2003; Sheng et al., 2003).

Wet perimeter and average width of the water surface were measured. Flows in concrete flumes were calculated with DSİ tables according to the depth of water in the canal, canal bed slope, and the type number of the concrete flume (Acatay, 1996). Evaporation loss (E) was considered zero for the purposes of the study. Moreover, because there was no flow into the segment from outside (I), or diverted from the segment (D), both values were considered zero.

In choosing the canal to be measured and the placing of the segments, the following were taken into consideration (Balaban, 1970; Ancid, 2003): i) the flow should be the normal operating condition of the canal, ii) there should be no change in water level during measurement, iii) there should be no water flow either from outside into the segment or from the segment to the outside, iv) there should be no disruption of the cross-sectional geometry of the segment where the measurement was taken and there should be nothing to prevent the flow, and v) the length of segment should be sufficient for measurement of conveyance loss.

Measurements were taken in this way from a total of 5 main canal segments, 2 on the left bank main canal and 3 on the right bank main canal. At the secondary level, measurements were taken from 14 segments, 8 on the left bank and 6 on the right bank. At the tertiary level, measurements were taken from 32 segments, including 13 trapezoidal canals and 7 concrete flumes on the left bank, and 12 concrete flumes on the right bank. In order to define the positions of the segments of the main and secondary canals, coordinates of the beginning and end of segments were determined by GPS.

Variance analysis under the randomised complete block design was carried out to determine whether there was any statistically significant difference in seepage loss between the canal types. When a significant factor was found in the variance analysis, comparisons between subgroup means were carried out using Duncan's multiple range test. Excluding the main canal, seepage loss was analysed, again, by variance analysis with 2 factors (canal shapes and canal types) and their interactions, to find out the significance of the factors and their interaction. Relationships between seepage loss and canal hydraulic characteristics for trapezoidal canals were obtained from correlation coefficients. All statistical analyses were carried out using SPSS (Release 8 for Windows, SPSS Inc., Chicago, USA, 1997).

Results and Discussion

This study determined conveyance loss at the main, secondary, and tertiary canal levels in the open canal irrigation network serving the land on the left and right banks of the Menemen Plain during the July and August 2003 irrigation season.

Conveyance loss in the left and right main canals is shown in Table 1. Conveyance loss for the left bank secondary canals is presented in Table 2 and loss for the trapezoidal tertiary canals is presented in Table 3, and those for concrete flume tertiary canals are presented in Table 4. Additionally, conveyance loss for the right bank, for both secondary and tertiary canals, is shown in Table 5.

Water Conveyance Loss in Main Canals

Water conveyance loss at the main canal level was found to be the lowest (0.5%, 0.0071 l s^{-1} m^{-2}) in the left main canal, and the greatest (8.6%, 0.0361 l s^{-1} m^{-2}) in the right main canal. The average of both canals was 3% (0.0141 l s^{-1} m^{-2}) (Table 1).

Total water conveyance loss determined for both canals, except segment 5, was lower than the Turkish average (0.0321 l s^{-1} m^{-2}) and higher than the seepage standard of USBR for concrete canals (0.00024 l s^{-1} m^{-2}) (Bekişoğlu, 1993).

The measured water conveyance loss showed an increase over the last 30 years when compared to the values of seepage determined for the concrete lined right main canal (0.0019 l s^{-1} m^{-2}) and the soil-lined left main canal (0.0045 l s^{-1} m^{-2}) by Şener (1976) during 1973-1974.

The conveyance loss determined was higher than the seepage limit value given by Kraatz (1977) (0.03 m^3 m^{-2} day^{-1} ≅ 0.0003 l s^{-1} m^{-2}) and that given by LWRRDC (2002) (0.0005 m^3 m^{-2} day^{-1} ≅ 0.00001 l s^{-1} m^{-2}). This shows that maintenance and repairs have to be performed on the main canals.

Table 1. Conveyance loss in the Menemen left bank and right bank main irrigation canals.

Segment No.	Canal name*	Coordinate Beginning of segment	Coordinate End of segment	Segment length (m)	Water depth (m)	Water Surface width (m)	average wetted perimeter (m)	Inflow ($m^3 s^{-1}$)	Outlow ($m^3 s^{-1}$)	Conveyance losses $l\ s^{-1}\ 1\ km^{-1}$	Conveyance losses % 1 km	Conveyance losses $l\ s^{-1}\ m^{-2}$
1	L	38°38.936' N 27°09.189' E	38°37.632' N 27°07.413' E	2 245	1.95	11.91	13.1	17.5195	17.3117	92.6	0.5	0.0071
2	L	38°36.694' N 27°04.477' E	38°36.947' N 27°03.929' E	1 040	1.52	10.75	11.8	11.4290	11.2742	148.8	1.3	0.0126
3	R	38°40.708' N 26°58.774' E	38°40.406' N 26°58.434' E	575	1.14	5.15	5.9	2.2076	2.1995	14.1	0.6	0.0024
4	R	38°39.400' N 26°57.671' E	38°39.123' N 26°57.439' E	540	1.00	4.62	5.2	1.5758	1.5414	63.7	4.0	0.0122
5	R	38°38.742' N 26°56.533' E	38°38.650' N 26°56.300' E	393	1.26	5.30	6.1	2.5385	2.4526	218.6	8.6	0.0361
Average										107.6	3.0	0.0141

* L: Left main canal; R: Right main canal.

Table 2. Conveyance loss in the trapezoidal secondary canals of the Menemen Left Bank Irrigation Network.

Segment No.	Canal name*	Coordinate Beginning of segment	Coordinate End of segment	Segment length (m)	Water depth (m)	Water Surface width (m)	average wetted perimeter (m)	Inflow ($m^3 s^{-1}$)	Outlow ($m^3 s^{-1}$)	Conveyance losses $l\ s^{-1}\ 100\ m^{-1}$	Conveyance losses % 100 m	Conveyance losses $l\ s^{-1}\ m^{-2}$
1	Ke	38°37.622' N 27°02.748' E	38°37.628' N 27° 02.495' E	345	1.20	5.43	6.10	2.4966	2.3243	49.9	2.0	0.0819
2	Ke	38°37.649' N 27°01.761' E	38°37.652' N 27°01.336' E	625	1.15	4.51	5.24	2.1695	2.0164	24.5	1.1	0.0467
3	Se	38°36.935' N 27°03.470' E	38°37.153' N 27°03.290' E	459	1.60	6.37	7.39	5.1026	5.0292	16.0	0.3	0.0216
4	Se	38°37.221' N 27°02.772' E	38°37.024' N 27°02.370' E	675	1.60	6.66	7.61	5.0648	5.0109	8.0	0.2	0.0105
5	U	38°36.829' N 27°03.907' E	38°36.545' N 27°03.638' E	662	1.31	7.40	8.26	5.8274	5.7499	11.7	0.2	0.0142
6	Sa	38°33.086' N 27°00.290' E	38°32.984' N 27°00.100' E	341	1.03	4.86	5.48	2.2405	1.9146	95.6	4.3	0.1744
7	Sa	38°32.279' N 26°58.745' E	38°32.179' N 26°58.557' E	325	0.66	3.60	4.01	0.9645	0.8751	27.5	2.9	0.0686
8	Ka	38°32.330' N 27°00.712' E	38°32.258' N 27°00.602' E	195	0.53	2.87	3.18	0.4366	0.3906	23.6	5.4	0.0742
Average										32.1	2.0	0.0615

* Ke: Kesikköy; Se: Seyrekköy; U: Ulucak; Sa: Sasalı; Ka: Kaklıç

Table 3. Conveyance loss in the tertiary trapezoidal canals of the Menemen Left Bank Irrigation Network.

Segment no.	Canal name*	Segment length (m)	Water depth (m)	Water surface width (m)	Average wetted perimeter (m)	Inflow ($m^3 s^{-1}$)	Outflow ($m^3 s^{-1}$)	Conveyance losses		
								$l s^{-1} 100 m^{-1}$	% 100 m	$l s^{-1} m^{-2}$
1	Ke-2	106	0.35	1.66	1.89	0.1180	0.1140	3.8	3.2	0.0200
2	Ke-18	145	0.41	1.67	1.91	0.0934	0.0777	10.8	11.6	0.0567
3	Ke-23/1	141	0.49	1.70	2.04	0.1303	0.1253	3.6	2.7	0.0174
4	Ke-16	109	0.25	1.45	1.66	0.0829	0.0763	6.1	7.3	0.0365
5	Se-1	328	0.52	1.80	2.13	0.1411	0.1356	1.7	1.2	0.0079
6	Se-31	193	0.54	1.70	2.14	0.2053	0.1597	23.6	11.5	0.1104
7	Se-36/1	230	0.51	1.38	2.04	0.1244	0.0942	13.1	10.6	0.0644
8	U-12	74	0.23	1.19	1.32	0.0442	0.0441	0.1	0.3	0.0010
9	U-20	104	0.44	1.78	2.05	0.1635	0.1564	6.8	4.2	0.0333
10	U-24	188	0.43	1.79	2.04	0.1584	0.1558	1.4	0.9	0.0068
11	Sa-2	145	0.58	1.65	2.02	0.2718	0.1789	64.1	23.6	0.3172
12	Sa-13	125	0.26	1.28	1.42	0.0857	0.0797	4.8	5.6	0.0338
13	Sa-17	164	0.38	1.67	1.66	0.1301	0.1104	12.0	9.2	0.0724
Average								11.7	7.0	0.0598

* Ke: Kesikköy; Se: Seyrekköy; U: Ulucak; Sa: Sasalı

Table 4. Conveyance loss in the tertiary concrete flumes of the Menemen Left Bank Irrigation Network.

Segment no.	Canal name*	Type no.	Segment length (m)	Slope (‰)	Conveyance loss	
					$l s^{-1} 100 m^{-1}$	%
1	Ke-7	180	50	0.80	3.8	4.2
2	Ke-15	315	50	0.83	14.0	8.4
3	Se-7	230	55	1.17	3.4	1.9
4	Se-4	180	100	0.87	2.4	3.0
5	Sa-5	600	45	0.07	9.9	6.9
6	Sa-9	450	50	1.00	7.1	2.0
7	Sa-13	450	100	0.17	13.4	9.3
Average					7.7	5.1

* Ke: Kesikköy; Se: Seyrekköy; Sa: Sasalı

Table 5. Conveyance loss in the secondary and tertiary concrete flumes of the Menemen Right Bank Irrigation Network.

Conveyance canal	Segment no.	Canal name	Type no.	Segment length (m)	Slope (‰)	Conveyance loss	
						$l\ s^{-1}\ 100\ m^{-1}$	%
Secondary	1	Y-4	450	85	0.10	4.4	3.7
	2	Y-5	315	100	1.20	12.0	5.4
	3	Y-6	230	125	0.96	7.5	5.7
	4	Y-7	180	75	0.23	1.5	4.6
	5	Y-9	135	50	2.68	4.7	3.6
	6	Y-15	315	50	0.15	0.5	0.9
Average						5.1	4.0
Tertiary	1	Y-13/B	800	105	0.90	13.3	2.3
	2	Y-7/2	135	75	0.33	2.7	10.6
	3	Y-13/B2-B3	315	65	0.33	2.0	1.8
	4	Y-13/B4	135	50	0.47	1.2	2.9
	5	Y-15/3	135	50	0.40	4.3	9.2
	6	Y-15/4	180	100	0.50	9.1	12.0
Average						5.4	6.5

The Water Conveyance Loss in the Secondary Canals

Water conveyance loss in the network at the secondary canal level in the left bank was the lowest (0.2%, 0.0105 $l\ s^{-1}\ m^{-2}$) in the Se-2 segment of the canal, and the greatest (5.4%, 0.0742 $l\ s^{-1}\ m^{-2}$) in the Ka-1 segment. The average was 2.0% (0.0615 $l\ s^{-1}\ m^{-2}$) (Table 2). In the secondary concrete flumes of the right bank network, water conveyance loss was the lowest (0.9%, 0.5 $l\ s^{-1}$ 100 m^{-1}) in segment Y-15 and the greatest (5.7%, 7.5 $l\ s^{-1}$ 100 m^{-1}) in segment Y-6. The average was 4.0% (5.1 $l\ s^{-1}$ 100 m^{-1}) (Table 5).

When the values of average conveyance loss of the secondary canals (Tables 2 and 5) are compared to the values in the main canals (Table 1), it is clear that the conveyance loss in the right bank concrete flume secondary canals was higher.

The average conveyance loss for trapezoidal secondary canals was higher than the average for Turkey, which Bekişoğlu (1993) stated as 0.0321 $l\ s^{-1}\ m^{-2}$, the average conveyance loss for the concrete secondary canals that Şener (1976) gave for the same network (0.0025 $l\ s^{-1}\ m^{-2}$), and the standard of seepage (0.00024 $l\ s^{-1}\ m^{-2}$) for concrete canals set by the Bureau of Reclamation (1975). Furthermore, conveyance loss in both concrete flume and trapezoidal type secondary canals was higher than the limit values given by Kraatz (1977) and LWRRDC (2002). This shows that the average conveyance loss for the secondary canals of the network has increased, and that maintenance and repair performance are insufficient.

Şanlı (1996) and Ünal et al. (1999, 2001, 2004) have reported that the increase and excess of conveyance loss are caused by seepage and damage to the concrete linings of trapezoid canals due to farmer interference, a high water table, cracks and leaking joints in the flumes, and deterioration of water sealing materials, as well as construction and operating mistakes.

The Water Conveyance Loss in Tertiary Canals

Water conveyance loss at the level of the trapezoidal tertiary canals in the left bank network was the lowest (0.3%, 0.0010 $l\ s^{-1}\ m^{-2}$) in segment U-12 and the greatest (23.6%, 0.3172 $l\ s^{-1}\ m^{-2}$) in Sa-2, with an average of 7.0% (0.0598 $l\ s^{-1}\ m^{-2}$) (Table 3). Water conveyance loss in the concrete flume tertiary canals on the same bank was the lowest (1.9%) in segment Se-7 and the greatest (9.3%) in section Sa-13, with an average of 5.1% (Table 4). Water conveyance loss in concrete flume tertiary canals on the right bank of the network was estimated to be the lowest (1.8%) in Y-13/B2-B3 and the greatest (12.0%) in Y-15/4, with an average of 6.5% (Table 5).

The average conveyance loss determined for the concrete lined tertiary canals of the network was above the values given by Bekişoğlu (1993) and Şener (1976). It was also found that the conveyance loss determined for both trapezoidal tertiary canals and concrete flume tertiary canals in the network were higher than the limit values set by Kraatz (1977) and LWRRDC (2002). This shows that canal maintenance is necessary to prevent losses, and that the factors that caused the above-mentioned conveyance loss had a greater effect on the tertiary canals.

Statistical Analysis of Seepage Losses

Descriptive statistics for seepage loss in different canal types and the summary of variance analysis results are given in Table 6. No significant difference ($P > 0.05$) for seepage loss was found among canal types.

Changes of seepage loss according to canal shape and type are given in Table 7. Additionally, average seepage loss in secondary and tertiary canals, which have trapezoidal and concrete flumes, is indicated in Figure 2.

From the overall means given in Table 7, it was determined that there was no significant difference for seepage loss between secondary and tertiary canal types ($\bar{X}_{secondary} = 18.600^{a} \pm 4.404$ and $\bar{X}_{tertiary} = 9.173^{a} \pm 3.199$). Similar results were obtained in the second analysis for comparison of canal types presented in Tables 6 and 7, as expected. In the comparison of the general averages of canal shapes, significant ($P < 0.05$) differences ($\bar{X}_{trapezoidal} = 21.892^{a} \pm 3.664$ and $\bar{X}_{concrete\ flume} = 5.881^{b} \pm 4.025$) were determined between trapezoidal and concrete flumes for seepage loss. The interaction between canal type and canal shape was significant ($P < 0.05$). In this case, instead of a comparison between averages of subgroup differences of each main effect, comparisons among the average differences for the combination of canal type subgroups and canal shapes were performed. From the comparisons, canal type was not significant for seepage loss in concrete flume canals ($\bar{X}_{secondary} = 5.100^{b} \pm 6.658$ and $\bar{X}_{tertiary} = 6.662^{b} \pm 4.423$), but the effect of canal type for seepage loss in trapezoidal canals was significant at the 5% level ($\bar{X}_{secondary} = 32.100^{a} \pm 5.766$ and $\bar{X}_{tertiary} = 11.685^{b} \pm 4.523$) (Table 7).

Figure 2 was created for a better understanding of the interaction between canal type and canal shape. The change in average seepage loss in trapezoidal canals from secondary to tertiary canals showed a sharp decreasing pattern, while a small increase for average seepage loss was determined in concrete flume canals from secondary to tertiary canals.

The relationships between seepage loss and canal hydraulic characteristics (flow, water depth, and average wet perimeter) in trapezoidal canals are given in Table 8. The relationships between seepage loss and hydraulic characteristics of the canals were not statistically significant.

Table 6. Descriptive statistics regarding seepage loss for different canal types ($l\ s^{-1}\ 100\ m^{-1}$) and variance analysis results.

Canal type	n	Mean	Std. Error	Minimum	Maximum
Main	5	10.756[a]	3.529	1.41	21.86
Secondary	14	20.529[a]	6.771	0.50	95.60
Tertiary	26	9.173[a]	2.448	0.10	64.10

[a], P > 0.05

Table 7. Changes in average and standard errors of seepage loss (l s^{-1} 100 m^{-1}) according to canal shape and type.

Source of variation		Canal shape						General		
		Trapezoidal			Concrete flume					
		n	$\bar{X}$	SE	n	$\bar{X}$	SE	n	$\bar{X}$	SE
Canal Type	Secondary	8	32.100[a]	± 5.766	6	5.100[b]	± 6.658	14	18.600[a]	± 4.404
	Tertiary	13	11.685[b]	± 4.523	13	6.662[b]	± 4.523	26	9.173[a]	± 3.199
General		21	21.892[a]	± 3.664	19	5.881[b]	± 4.025	40	13.887	± 2.722

[a, b]: Means with different superscripts within the same source of variation in the same columns were significantly different ($P < 0.05$)

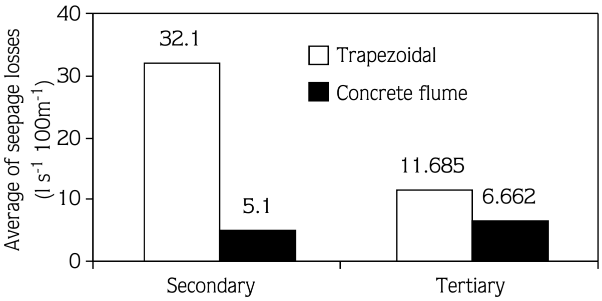

Figure 2. Change in average seepage loss according to canal shape and type.

Table 8. The relationship between seepage loss and canal hydraulic characteristics of trapezoidal canals (n = 26).

Hydraulic characteristics of canals	Correlation coefficient (r)
Inflow	–0.019[NS*]
Water depth	0.160[NS*]
Average of wet perimeter	0 095[NS*]

[* NS] $P > 0.05$

Conclusions

In this study, water conveyance loss was determined for the canals that convey and distribute water in the Menemen Plain open canal irrigation network. The state of maintenance of the canals was evaluated by comparing the values of the conveyance loss in the main, secondary, and tertiary canals to each other, with the reference values of water conveyance loss in the open canals, and with conclusions reached in other studies. In addition, seepage loss was statistically tested.

The average values of water conveyance loss in the network were higher in both secondary concrete flumes and trapezoidal concrete flume tertiary canals than in the main canals.

It was also found that the values for secondary canals were lower for trapezoidal canals than for concrete flumes and the values for tertiary canals were higher for trapezoidal canals than for concrete flumes. Moreover, it was determined that the average water conveyance loss determined for all open canals in the network was higher than the average value of 30 years ago, the current average value of networks in Turkey, and the seepage standard and limit values that indicate adequacy of maintenance and repair. The increase and excess in conveyance loss shows that renovation work, which was conducted on conveyance canals in certain parts of the irrigation area during land consolidation, and maintenance and repair work done by the WUAs were insufficient.

It was determined that there was no significant difference for seepage loss between secondary and tertiary canal types, in general. There was a significant difference ($P < 0.05$) between the canal shapes (trapezoidal and concrete flume) for seepage loss. On the other hand, the interaction between canal type and canal shape was significant ($P < 0.05$). The change in average seepage loss in trapezoidal canals from secondary to tertiary canals showed a sharp decreasing pattern, while a small increase for average seepage loss was found in concrete flume canals from secondary to tertiary canals.

Taking the seepage loss that occurred from unit lengths of the main, secondary, and tertiary canals, and total lengths of the canals of the system (776,354 m) into consideration, the amount of the water loss by seepage can be realized. Such water loss causes huge economic and environmental problems. In order to prevent such problems, certain measures should be taken.

The limited budgets of the WUAs make it difficult to carry out work, such as renovating either the old canals left out of the consolidation or the canals renovated and lengthened as part of the consolidation, or converting the canals to a piped system. The feasibility of new economic measures to reduce water conveyance loss in the network has to be studied. For this reason, the following measures may be suggested as a start: i) install concrete linings with new concrete mixtures that are able to withstand the effects of water and soil, and that have been determined to be more effective in terms of seepage; ii) use canal linings that are more economical, more effective, more durable, and longer-lasting; and iii) make sure farmers do not damage the canals when they get water from them and while engaging in other agricultural activities.

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