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# Estimation of Conveyance Losses of Wonji-Shoa Sugarcane Irrigation Scheme, Ethiopia

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**Abstract**
To estimate the amount of conveyance losses through earthen canals and canal structures of Wonji-Shoa irrigation scheme, a study was conducted during irrigation season of 2010/2011. Current meter was used to collect discharge measurements from several locations and inflow-out flow technique was applied to estimate seepage and leakage losses. Seepages from fine textured or clay soils of selected primary, secondary, and tertiary canals while leakages from division structures, gates, broken canals and over flow on top of canals were determined. From the study, it was found that mean conveyance losses through seepage and leakages were 2,099.33 lit/day/m$^2$ or 12.36% and 48.82 lit/sec or 11.23%, respectively. Mean canal water velocity was 0.23 m/sec which is much below recommended value for fine textured soil. Even though seepage was related with discharge capacities of canals, it was aggravated by slow water velocity. Deformed and oversized canal conditions and poorly maintained water controlling structures were hampering smooth water flow of old aged canal networks of the scheme. To minimize the losses, rather than lining of selected canal by geomembrane, rehabilitating of the entire canal system is recommended as best option due to nature of canal system of Wonji Shoa irrigation scheme.
**Keywords:** conveyance, seepage, Wonji-Shoa, current-meter, Ethiopia

## Introduction

Most irrigation projects of more recent times nearly always received their water by diversion from rivers or from reservoirs and the main mechanism for the conveyance of water to farms is through earthen channels. The water losses which occurred in conveying water to the tertiary offtakes via main, lateral, and sub lateral canals were often substantial.

In the context of irrigation-water supply, conveyance losses are reported as the difference between the volume of water supplied to irrigation customers and water delivered to the system (Erhan et al., 2007); and it takes the following forms; oufall or water flowing out of the downstream end of delivery systems, unrecorded usage, seepage, leakage, evaporation and others. The most important of these are seppage and leakage. Seepage is the movement of water throught the beds of irrigation channels while leakage is the loss of water from channnels therough channel banks and structures. Bothe together called canal conveyance losses. Evaporation loss in irrigation network is generally not taken into consideration (Xie et al., 1993).

Recent studies have indicated that estimates of conveyance losses are an essential component in the management of earthen channel systems for several reasons: loss of an economically valuable resource the need to halt environmental decline with in our waterways and; contribution to groundwater recharge and associated induced water logging and land salinisation (ANCID, 2000)

Seepage rates from irrigation channels vary from site to site depending on local conditions. In general, an existing unlined channel in clay soil would have low levels of seepage by in clayey loam it might lose about 150 lit/m$^2$/day, about 250 lit/m$^2$/day in sandy loam and 750 lit/m$^2$/day or more in sandy or gravelly soil (Swan, 1978). A comprehensive review by the Victorian Rural Water Commission of channel seepage measurements taken between 1962 and 1983 across the Goulburn Murray Water region found that measurements of channel seepage ranged from 2.4-116 lit/day/m$^2$ (Dunstone, 1998). In very gravelly soil, seepage rates could reach up to 914-1,829 lit/day/m$^2$ (Davis, 1952). Another sources reported that the total amount of water lost by seepage from unlined irrigation canals are between 20 to 60% of the total amount of water diverted at the head of the system (Kraatz, 1977).

According to Akbar (2003), factors determining the amount of seepage in an unlined canals can be classified as the following four groups: soil and lining characteristics; geometry and hydraulics of the canal; sediment characteristics and; service year of the canal.

The decision whether to line canals or not is an economical one. The relevant factors for the decision are; permeability and resistance of the soil for erosion; cost of water and; the amount of water available for diversion. The decision could be either of the following; installing clay, geomembrane or concrete lining, or pipe lining, secions of channel in zones of high seepage; repairing and rehabilitating channel banks and structures and; improving the accuracy of meters on farm irrigation outlets.

At Wonji Shoa Sugar Estate, an open canal surface irrigation system was developed and furrow irrigation was carried out for the last 61 years. According to Mukherji (2001), most of the irrigation canals of the scheme have lost their original dimensions. Main canals are silted up and most of them are flowing up to the brim i.e. there is no freeboard available. Supply of water to the tertiary from secondary canals also has the same problems. Hydraulic performances study of the canals, conducted by Habib (2005), suggested that non uniform top and bed dimensions; absence of measuring structures; siltation of reservoirs and canals; and seepage losses from canals were the main problems for proper water management operations and were causes for shallow groundwater table of the irrigation fields. A study conducted on identifying causes of ground water rise by Yusuf et al. (2010) also identified that applications of excess irrigation water and seepage from canals were major causes which are related to poor water management practices.

Based on conditions of canals and visual observations, various reports have estimated that losses from supply canals may reach up to 20% to 40%, but the actual figure have never been quantified yet. Therefore, this study was carried out to quantify conveyance losses and to develop a relationship between surface velocity with mean velocity of the canals.

**Materials and methods**

*Descriptions of the study area*

Wonji Shoa Sugar Estate is located in the central rift valley of Awash River basin around 107 km south east direction of Addis Ababa, exactly in $8^{0}30'$ to $8^{0}35'$ N and $39^{0}10'$ to $39^{0}20'$ E at an altitude of 1540 m a.s.l. Currently, sugarcane plantation is continuously expanding and reaches more than 10,000 ha (as of June 2012). Out of which 7,022.15 ha is under surface irrigation system while the rest is using sprinkler irrigation system. Mean maximum and minimum temperature of the area are $27.6^{0}$C and $15.3^{0}$C with 820 mm of annual rainfall. Mean evapotranspiration reading of the area is around 4.6 mm/day.

Water for the surface irrigation scheme of the estate is conveyed from a main pump station through 480 m long concrete lined canal (Figure 1). The main canal branches out into left and right directions. The braches further reduce to supply canals of four categories that have discharge capacities of 600, 525, 300, and 150 liter/sec and called as very big, big, medium and small canals, respectively (Mukherji, 2001). The respective total length of each canal category of Wonji Shoa irrigation scheme is 40,492 m, 36,627 m, 113,929 m and 84,060 m. Out of the total 275,208 m long earthen canal distributing water throughout the scheme, currently few canal networks are covered with geomembrane plastic. Soils of the whole canals system is categorized as clay or fine textured constructed on very flat plain having longitudinal slope of 0.05 to 0.06%.

The maximum design capacity of the main supply canal is around 5.16 $m^3$/sec and is intended to be served by nine electric pumps. Water supply to the distribution system is controlled using locks or control structures where weir and/or check gates are employed. On the other hand, the system is continuously supplying water with mean flow rate of 2.5 to 3.5 $m^3$/sec for sugarcane fields except the rainy season. Field irrigation is carried out for 8 hours of daytime (WSF, 1993). To avoid water shortage, there are five reservoirs on 55 ha of land with storage capacity of more than 400,000 $m^3$. There are also seven small reservoirs on 13.5 ha of land to serve around 610 ha of sugarcane fields.

Sugarcane fields of the estate are divided into three irrigation sections (R, L and E). Each irrigation sections are further divided into three sub irrigation blocks. Each block comprises square shaped (approximately 500 m by 500 m) fields that are separately served by a tertiary canal.

*Methodologies*

The study was carried out during the irrigation season of 2011. Representative canals were selected based on accessibility; shapes and dimensions; discaharge capacities and so on. Seepage and leakage losses were measured from a total of 22 (8 from main; 7 from secondary and 7 from tertiary canal segments) and 16 locations, respectively. Losses due to evaporation were not considered with the assumption of its negligible proportion.

In choosing the canal to be measured for seepage, the following were taken into consideration (ANCID, 2003); i) the flow should be at 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 nothing to prevent the flow, and v) length of segment should be sufficient for measurement of conveyance loss.

Technique appleid to determine both seepage and leakage losses was inflow-outflow method in which water that flows into and out of canal sections and canal strutcures were measured. For seepage measurement canal length between two points were determined using a tape meter. While for leakage quntification, discharges were measured before and after canal structures such as off takes, division poxes, gates structures, damaged canal sections.

During each measurement, based on size of the canals, top widths of water surfaces in the canals were partitioned at 20 to 30 cm intervals. At the same time water depths of each section were measured and cross sectional areas of each partition were determined.

To collect discharge measurement without affecting canal operations, model CMC-200 current meter was used for the study and the equations being applied for determining velocity of water were (Ministry of Environment, 1998):

$$V = 0.2455n + 0.014, \quad if\ n < 0.64$$
$$V = 0.2595n + 0.005, \quad if\ n \geq 0.64$$
……………………………eq(1)

*Where: 0.2455 and 0.2595 are the coefficient of the propeller type and 0.014 and 0.005 are coefficients 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/sec). Numbers of propeller revolutions were counted for an interval of 40 seconds.*

For canals greater than 0.6 m deep, flow velocities were measured at 0.2 and 0.8 of full depths from surface while at 0.6 full depths for shallower canals (USBR, 1976). Discharges of each partion, calculated using velocity-area method, were summed up and taken as flow discharges of the canal.

Conveyance or seepage losses in the canals were quantified with percent losses, losses in $m^3$/day/$m^2$ of wetted perimeter and losses lit/sec/km of canal length (Kraatz, 1977) while leakage losses were described as percent losses. Data from various canal sites were discarded due to significant anomalies and repeated measurements were taken.

After categorizing the canals into main secondary and tertiary, measurements from all segments were averaged and losses were determined for each category.

In order to relate mean canal water velocities of current meter with surface water velocities, by selecting straight segments of a specific canal length and using floating materials, time taken to travel the segments were measured simultaneously at each seepage measurement point.

Multiple or stepwise regression technique was used to determine coefficients of canal characteristics such as canal dimensions, water velocities, and discharge capacities together with their relative importance on seepage losses at 90% confidence intervals. Finally, suggestions regarding need of rehabilitation work for the canals were forwarded.

**Result and discussion**

From previous studies and hand feel method, soils of the canals in the estate were classified as very fine textured clay soils with low permeability values. Within canal networks of the estate from which measurements were taken, depth of the canals varied from 0.37 upto 1.1 m while canal widths were in the range of 0.9 up to 5.3 m. The smallest discharge being measured was 33.1 lit/sec on tertiary canal around field number 86 while the biggest was 2,667.2 lit/sec on the main supply canal. Accordingly, based on collected discharge capacities, the entire canal network was grouped into three categories as main (> 600 lit/sec) , secondary (300 to 600 lit/sec) and tertiary (less than 300 lit/sec) canals (Table 1).

*Conveyance losses*

As stated previously conveyance losses constitute mainly seepage and leakage losses. Seepage is refering to water losses through canal beds and sides while leakage losses constitute wastage of water through canal over flow, leakage through gates, diverison structures, broken canals and so on. Results of seepage and leakage losses are presented separately as follow.

**Seepage losses**

From the data collected, losses through seepage were in the range of 790.75 lit/day/$m^2$ around field number 16 to 5,223.5 lit/day/$m^2$ around field number 141 with mean value of 2,099.33 lit/day/$m^2$. Similarly, in percent bases seepage losses were in the range between 7.26 to 28.36%. Water velocities of all canals were in the order of 0.11 to 0.35 m/sec with mean value of 0.23 m/sec. Accordingly, mean seepage losses from the entire canal networks were much higher than standard of USA for unlined canals of clay soils.

For canals of clay soil, the recommended velocity and expected losses are within the ranges of 0.5 to 0.8 m/sec and 80 to 110 lit/day/$m^2$ wetted perimenter, respectively (USBR, 1976).

Among many contributing factors for water losses through seepage at Wonji Shoa irrigation scheme, deformed and oversized canals are the major ones in which velocity of water was very slow providing an opportunity time to percolate through beds and sides of canal. In addition, existence of densly grown eucalyptus trees and weeds along most of canal embankments as well as canal beds were also escalating the losses.

**Losses through leakages**

Leakage losses were in the ranges of 19.2 lit/sec or 0.72% at the junction of KW1 to 81 lit/sec or 18.79% around a community area along the canal to Shoa factory with mean value of 48.82 lit/sec or 11.23%. Leakage losses were occurred due to malfunctioning or failure of offtake structures, division structures and gates; overflow of irrigation water on top of damaged canals; and abstruction of water by unauthorized users for household consumptions.

Most of irrigation structures are either not present or not functioning properly. It is common to see canal breaches; muds and woods are serving as water controlling structures and; considerable amount of water flowing into drains. Flow of large amount of unmanaged water into drains were significant when visually compared to seepage losses.

**Characteristics of canal network of the estate**

As indicated below results of stepwise regression analysis (Table 2), water losses through seepage were highly correlated (*p*=90%) with discharge capacities followed by velocities of water in the canals. Seepage losses decreased as flow discharge decreased. With the same fashion, flow velocities of water in the canals were inversly related with seepage losses.

Classifying shapes of the canals in the estate either as trapizoidal or rectangular is very difficult due to the fact that they have lost their original shapes through repeated silt removing operations. Dimensions of the canals may vary within short distances, exceptionally however, few canals exists with uniform shapes. Canals sides are covered with big eucalyptus trees while weeds and shrubs are populating canal beds. Roots of the trees are affecting maintainace operations as well as hindering water flows. On top of that muds and sediments which were removed from canals and mounted up along canal banks, has also played significant roles for deforming and oversizing of canals. As a result canal are serving as a reservoir and hardly be free of stagnated water. The problems are similar to all canals irrispective of their size and locations.

In recent time by regonizing the problem, Wonji Shoa sugar estate has started geomembrane lining of highly affected canals. Although geomembrane is better than others methods because of its durability (40-60 years), low maintenance costs and high efficiency (95% seepage reduction) (ANCID, 2003), a number of factors should be considered in the process of determining the appropriate method for a particular site. Site-specific details need to be considered in order to determine which technique is appropriate.

Even if lining of a single canal with geomemebrane may reduce seepage of that particular canal, it will not help to minimize the problem of the estate as whole. Among many factors, sediment load from earthen canals of the upper reaches will be accumulated within geomebrane lined canals and mechanical desilting will be difficult; water will be filled up backward and stored in the canal if any barrier exists across down stream canals as observed in the scheme; due to seepage of unlined canal ground water uplift will be developed to damage the geomembrane.

Rather than geomembrane lining of selected canal segments, proper reshaping and reconstruction of conveyance systems of the estate on the existing soil materials are very helpful to minimize seepage. Because soils of the canals are fine textured with low permeability. Reshaping and rehabilitating of the canal network without using any lining material can be done phase by phase strating from the main canals down to tertiary canals.

According to ANCID (2004) if a canal network is near the end of its useful life, seepage may be addressed by remodelling of the canals.

**Relationship of surface velocity and mean velocity of water in the canals**

During the determination of seepage and leakage losses, surface velocities of water flowing in the canals were determined around 34 locations using floating materials. Surface velocities of the water and mean velocities of the canals were correlated and a relationship was developed which could help quick estimation of canal discharges.

The relationship between the two velocities has the following nature with correlation coefficient ($r^2$) of 0.904.

$$Y=0.7658x \quad \text{.......................................eq.(2)}$$

*Where: Y denotes mean velocity of canals while x denotes surface velocity of the water in the canals.*

From the result, it was found that the ratio of mean velocity water in each canal category to surface velocity is 0.765, which means at current condition of the canals of the estate surface velocities were 31% faster than mean canal velocities.

**Conclusion and recommendations**

Without considering unaccounted losses such as flow into drains as well as field losses, mean conveyances losses from main, secondary, and tertiary canals of Wonji Shoa surface irrigation scheme is 23.58% of diverted water at the main pump station. Losses through seepage and leakage are contributing almost the same shares.

Canal performances were highly affected by deformed canal shapes and trees grown along canal embankments which is manifested by very slow water velocity. Leakages because of damaged canals, canal breaches and broken structures were also causing large quantities of water to be wasted. Such conditions lead not only to inadequacy, but also to inequity, in water supply.

The need for rehabilitating the irrigation system demonstrate that the system has previously not been properly maintained and control structures are frequently reported as being either in a very poor condition or very inoperable. Moreover, addressing of the entire canal network is necessary due to the fact that seepage and leakage are not limited to specific canal category and to some parts of canal network. Most of the canals and canal structures have problems with comparable magnitude.

Rehabilitating of the canal system without any lining materials is much preferable than covering selected canals with geo-membrane. The work must be started from upper reach of the scheme and should go down to smaller canals following topography and discharge capacities. Besides, repairing of water controlling structures at each junction along the way should be carried out simultaneously.

For the existing canal configuration, quick discharge estimation can be carried out using floating method considering surface velocity correction factor of 0.7658.

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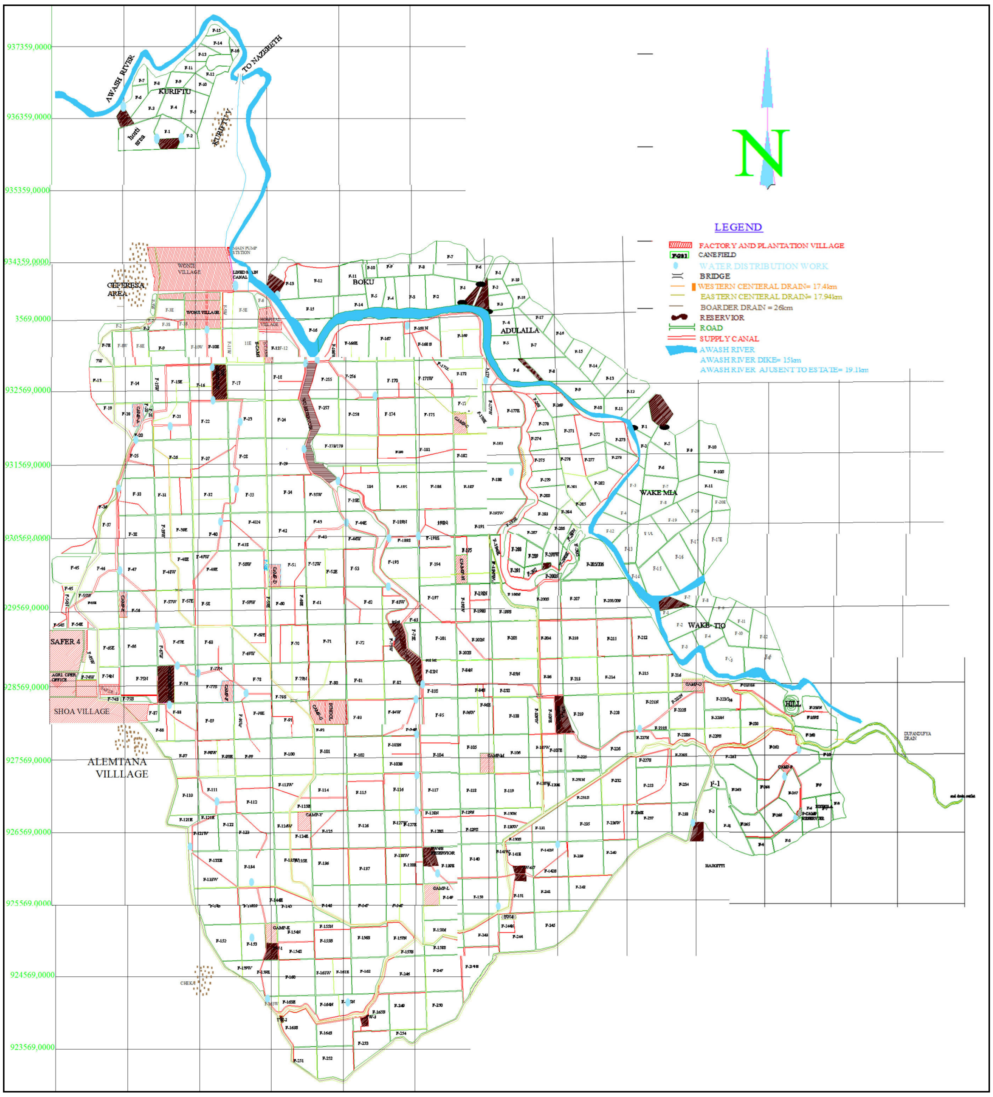

Figure 1. Canal layout of Wonji Shoa irrigation scheme

Table 1. Mean canal characteristics and seepage losses from each canal categories of Wonji Shoa irrigation scheme

| Canal categories | Capacity, lit/sec | Depth, m | Width, m | Wetted perimeter, $m^2$ | Velocity, m/sec | Discharges, lit/sec | Length, m | Losses | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | lit/sec | lit/sec/km | lit/day/m2 | % |
| Main canals | >600 | 0.92 | 3.58 | 5.21 | 0.24 | 881.53 | 828.57 | 120.40 | 148.27 | 2,507.69 | 11.88 |
| Secondary canals | 300 to 600 | 0.83 | 2.22 | 3.75 | 0.24 | 437.55 | 649.13 | 73.32 | 127.51 | 2,194.72 | 13.68 |
| Tertiary canals | <300 | 0.85 | 1.37 | 3.08 | 0.22 | 204.66 | 478.86 | 27.24 | 65.19 | 1,595.58 | 11.51 |
| **MEAN** | | | | | **0.23** | | | | **113.66** | **2,099.33** | **12.36** |

Table 2. ANOVA table of seepage losses in liter per second for canal velocities and discharges

| | df | SS | MS | F | Significance F | |
|---|---|---|---|---|---|---|
| Regression | 2 | 42179.32 | 21089.66 | 18.09 | 3.993E-05 | |
| Residual | 19 | 22150.699 | 1165.83 | | | |
| | Coefficients | Standard Error | t Stat | P-value | Lower 90.0% | Upper 90.0% |
| Intercept | 53.15 | 27.65 | 1.92 | 0.0697 | 5.34 | 100.95 |
| Velocity, m/sec | -214.38 | 113.34 | -1.89 | 0.0739 | -410.36 | -18.41 |
| Discharge, lit/sec | 0.14 | 0.02 | 5.96 | 9.889E-06 | 0.098 | 0.18 |

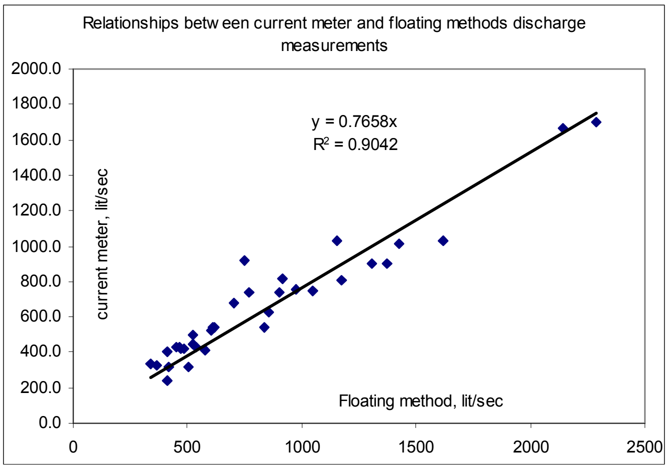


Figure 1. Graph showing the relationships between mean water velocity and surface water velocity of canals