MEASURING SEEPAGE RATES FROM IRRIGATION CANALS

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PREFACE

This study was made to measure the seepage rates from irrigation canals in the Altus area of southwestern Oklahoma. Seepage rates were measured by seepage meter and ponding methods.

I wish to express my appreciation to my major adviser, Dr. D. L. Nofziger, for his guidance and assistance throughout this study. I also wish to express my appreciation to the other committee members, Dr. L. M. Verhalen and Dr. C. E. Rice, for offering invaluable suggestions in the preparation of the final manuscript.

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CHAPTER I

INTRODUCTION

Seepage from irrigation canals is a problem of considerable importance. It has been estimated that one-third to one-half of all water diverted for irrigation is lost in conveyance due to seepage (Rasmussen and Lauritzen, 1953).

Seepage from irrigation canals may also cause the water table to rise. An increase in water table elevation generally increases water evaporation from the soil surface. This tends to bring saline or alkali salts to the soil surface which may then damage crops and soils. These salts are often difficult and expensive to remove. Seepage may also cause waterlogged areas in the neighborhood of the canal.

This research was conducted to determine the magnitude of seepage losses in irrigation canals in the Altus area of southwestern Oklahoma. Experiments were conducted to measure the seepage rate from selected irrigation canals on the Oklahoma Agriculture Experiment Station near Altus. Measurements were also conducted on a canal north of Altus. Seepage meters were used in two sections of the main irrigation canal and one small canal. Infiltration rate was measured in two sections of the irrigation canal before they were filled with water. The infiltration rate indicates rate of water movement from the canals during the first few hours after they were filled.

CHAPTER II

LITERATURE REVIEW

Seepage Losses

Robinson and Rohwer (1959) defined seepage as the movement of water into or out of irrigation canals through the bank materials. If the groundwater level is below the water surface in the canal, water will seep out of an irrigation canal, but if the water table is above the water surface in the canal, water will seep into the canal from the surrounding area.

Many factors influence seepage rates from irrigation canals; e.g., the texture of the soil. A literature survey by Worstell (1976) indicated that seepage rates as measured by the ponding method were 7 cm/day in clayey soils, 24 cm/day in silty soils, 29 cm/day in loamy soils, and 48 cm/day in sandy soils. These results indicate that seepage rates increase rapidly as the texture of the soil changes from fine to coarse.

Etcheverry (1933) indicated that an increase in temperature increased the rate of seepage by decreasing the viscosity of water. However, Robinson and Rohwer (1959) found that an increase in temperature caused air bubbles in the soil to expand, blocking pores in the soil which decreased seepage rate. Masonyi (1963) indicated that suspended silt and dissolved salts carried by water in the canal gradually settled and sealed the canal bed and sides and resulted in decreased seepage rate. Although velocity of water in the canal affects erosion, sedimentation, and the wetted soil perimeter, Bouwer, Myers, and Rice (1963) did not find any measurable direct effect of velocity on seepage. Etcheverry (1933) indicated that the seepage rate increased as the depth of the water in the canal increased.

Many methods of measuring seepage rates from canals have been proposed and utilized. Each method has advantages and disadvantages. The most common methods are the inflow-outflow, the ponding, and the seepage meter methods. Other methods less commonly used include the well-permeameter, the laboratory permeability, in situ measurement of permeability, groundwater elevation, electric logging (Robinson and Rohwer, 1959), and radioisotope (Krishnamurthy and Rao, 1969) methods. In this chapter, only the three major methods will be reviewed.

The inflow-outflow method involves measuring the rate of water flowing into a section of the canal and the rate of water flowing out of that section. The difference is the seepage rate (Hogan, Haise, and Edminster, 1967). Correction for evaporation and rainfall must be made. Usually, current meters are used to measure the rate of water flowing in the canal because no head loss is required to make the measurement, and the meters are relatively cheap and easy to operate. If canal conditions permit, weirs,parshall flumes, gates, and valves can also be used to measure the inflow and the outflow rates (Warnick, 1951). There are some advantages to using the inflow-outflow method. Brockway and Worstell (1968) found that for canals with large seepage losses, the inflow-outflow method may be the most expedient and expectantly accurate. Advantages listed by Warnick (1951) include the fact that seepage is measured directly during normal canal operation so that no correction is needed for unusual flow conditions. Also, inflow-outflow measurements do not interfere with the water deliveries of the canal. On the other hand, Brockway and Worstell (1968) did state that this method should be used only in long sections of canals to obtain good results. However, Robinson and Rohwer (1959) did state that this method can be used in short sections of canals in which seepage is taking place at high rates. Warnick (1951) found that the inflow-outflow method was not expectantly accurate in most cases, and should be used only in long sections of canals with homogeneous soils. Warnick (1951) stated that this method indicates only an average loss over a considerable length of canal, and can be used only during the irrigation season.

The ponding method offers the most accurate means of evaluating seepage loss (Warnick, 1951). The measurements are made by sealing off a section of canal with a watertight structure. The section is then filled with water, and the rate of water loss is determined by observing the drop in water level as a function of time. All leaks from the section must be measured carefully; evaporation and rainfall must be recorded to correct the drop in water surface. A water stage recorded can be used to monitor continuously the elevation of water in the canal.

Robinson and Rohwer (1959) stated that the ponding method produces an accurate result for seepage rate measurements. This method is used as the standard of comparison for seepage results obtained with other methods. It can be used for measurements in small localized areas (Warnick, 1951). Brockway and Worstell (1968) stated that although ponding is the most accurate method known, it is also the most expensive. Robinson and Rohwer (1959) indicated that it is very expensive to construct the dams required, and it is difficult to fill the canal after the dams are constructed. Experiments done by Warnick (1963) in four specially prepared sections of canals illustrate another problem with ponding. In this experiment, four 61 m-long sections were separated by watertight bulkheads. The sections were thought to be identical, but seepage rates were measured individually for all four sections. The seepage loss for the four sections varied from a high of 33.22 cm^3/cm^2/day to a low 12.50 cm^3/cm^2/day. Thus, even though the canal sections were considered identical, large differences in seepage rates between sections were measured. Bouwer and Rice (1968) stated that the canal must be taken out of operation during ponding measurements, and the lack of water movement causes silt to accumulate on the canal bed which can decrease seepage rate and may cause the normal seepage rate to be underestimated. This was the reason Warnick (1963) used four sections of canal rather than repeating measurements on one section. The ponding method ignores any effect of water velocity on seepage. The ponding method cannot be used in large canals because of the difficulties in constructing dams and filling the canal with water (Warnick, 1951).

Brockway and Worstell (1968) compared the inflow-outflow and ponding methods for measuring seepage in a 7.25 km section of a canal. The seepage rates determined by inflow-outflow were higher than those found by ponding by 18.30 to 21.34 cm^3/cm^2/day.

The seepage meter method is the most common method used for measuring seepage rate from irrigation canals. In this method, a cylindrical cup is pressed into the canal bed. The top of the cup is attached by means of a flexible tube to a plastic bag filled with water floating in the canal. As water seeps from the cup into the ground, water is drawn from the plastic bag to replace the water which is lost by seepage. The amount of water moving through the soil under the cup is determined by weighing the bag at the beginning and at the end of the test (Robinson and Rohwer, 1959).

Seepage meters provide the easiest and cheapest method known for measuring seepage rates. The measurements can be made under operating conditions at normal water levels in most canals. The losses can be measured for small areas and thus can be used to indicate specific regions where seepage losses are very great. The measurements can be made at any time the canal is filled with water without large labor or equipment costs (Rasmussen and Lauritzen, 1953).

The main problem with the seepage meter method is its accuracy. Warnick (1951) indicated that use of the seepage meter could not be merited to determine total quantity of seepage loss unless other methods could not be used. Rasmussen and Lauritzen (1953) suggested that the results obtained by the seepage meter cast considerable doubt on the reliability of this method for estimating seepage losses from irrigation canals. Robinson and Rohwer (1959) found that seepage meters do not accurately measure seepage, but they do indicate the order of magnitude of seepage rates. The seepage meter method cannot be used in rocky or rubbly perimeter canals, nor in canals with flow velocities higher than 35 m/min (Worstell, 1976).

Bouwer (1963) indicated that major sources of error in measuring seepage with the seepage meter are due to disturbing bottom material of the canal when the meter is installed, pressure distortion around the seepage meter by water flowing in the canal, or the difference in water pressure inside vs. outside the seepage meter. Kraatz (1977) indicated that disturbing the bottom material when the meter is installed could be minimized by using sharp-edged seepage cups and by forcing them into the soil by standing on them instead of by hammering them in. Bouwer, Myers, and Rice (1963) found that the head disturbance increased as the velocity of water increased, as the size of the seepage meters relative to the canal cross-section increased, and as the depth of seepage cup penetration decreased. However, they found that pressure disturbance effect around the seepage cup on the measured seepage can be ignored if the hydraulic gradients are more than one.

To solve the problem of head difference inside vs. outside the seepage meter, another kind of meter is sometimes used, called a falling head seepage meter. Here, the seepage cup is connected to the falling level reservoir (Bouwer and Rice, 1964). Before seepage is measured, the water level in the reservoir is raised about an inch above the water surface in the canal. A vacuum inverted U-tube manometer is placed on the canal bank. One leg of the manometer is connected to the seepage cup, the other to the free water in the canal. As water seeps into the soil, the water level in the manometer tube connected to the seepage meter falls, while water in the tube connected to the free water surface in the canal rises. The difference between the water levels in the manometer tube at any time is equal to the pressure difference between that in the seepage meter and in water in the canal. Seepage can be calculated graphically or analytically from measurements of water level in the manometer as a function of time (Kraatz, 1977). This falling head meter eliminates the problem of pressure differences between the inside and the outside of the seepage meter. Also an imperfect installation of the seepage meter can be detected immediately (Bouwer and Rice, 1964). However, this method cannot be used in a canal with water depth more than 60 cm (Kraatz, 1977).

A review and summary of 571 seepage tests made by Worstell (1976) in the western part of the United States by using both seepage meter and ponding methods in unlined canals indicated that the average value obtained by seepage meters tends to be quite close to the values obtained by ponding. His results are shown in Table I. These results were taken from different canals; therefore they do not give a precise comparison of the two methods.

TABLE I

SEEPAGE RATES OF GENERAL SOIL GROUPS
(Worstell, 1976)

General Soil Group	Ponding Tests		Seepage Meter Tests	
	Number of Tests	Average Rate (Meters/day)	Number of Tests	Average Rate (Meters/day)
Clayey	20	0.07	3	0.20
Silty	120	0.24	16	0.17
Loamy	196	0.29	11	0.26
Sandy	77	0.48	28	0.58

Infiltration Rate

The United States Salinity Laboratory staff (1954) defined infiltration rate as the rate of water entry into the soil where water covers the surface at a shallow depth and downward flow into and through the soil is nondivergent. The latter condition is satisfied by rainfall or by ponding an infinitely large area of soil.

Lewis and Powers (1938) stated that infiltration rates increase as soil becomes more coarsely textured and more open structured. Israelsen (1950) stated that infiltration increases as the depth to the water table increases. Israelsen and Hansen (1962) indicated that infiltration rate decreases with time of wetting; it also decreases as the initial moisture content increases. The presence of impermeable layers in the soil profile also tends to reduce the infiltration rate. Hillel (1971) explained that infiltration rate decreases with time because the potential gradient decreases with time. Water moves into an initially unsaturated soil due to matric and gravitational potential gradients. The matric gradient decreases as the wetted zone of the profile lengthens; it continues to decrease until it becomes negligible. This leaves the constant gravitational gradient as the only remaining force moving the water downward in the soil.

Miller and Gardner (1962) studied the effect of soil stratification on infiltration. They found that the infiltration rate decreased when the wetting front reached a clay layer which impedes flow due to its lower saturated conductivity. They observed that the rate of infiltration continued to decrease after reaching the clay layer. The infiltration rate also decreased when the wetting front reached a sandy layer where unsaturated conditions prevail owing to the lower unsaturated conductivity of sand. However, infiltration rate increased rapidly when water finally did move through the sand layer. Edwards and Larson (1969) indicated that when the soil surface is compacted and the profile is covered by a surface crust of lower conductivity, infiltration rate is lower than that of a more uniform soil.

CHAPTER III

MATERIALS AND METHODS

Two sections of the main irrigation canal and one section of a small canal located on the Oklahoma Agriculture Experiment Station near Altus, Oklahoma, were selected for this study. The soils surrounding these canals were Tillman and Hollister clay loams (Typic and Pachic Paleustolls). Measurements were also taken on a large canal north of Altus in a Miles fine sandy loam (Udic Paleustalfs) soil. The identification and dimensions of the selected canals are provided in Table II. Detailed descriptions of the soils surrounding the canals and of the canal locations are given in the appendices.

Seepage Rate Measurements

A large number of low-cost seepage meters were constructed. The seepage meters were made from empty paint buckets 28 cm in diameter and 35 cm in height. After cleaning the buckets, two connectors were mounted in the buckets. One connector was used to bring water from the floating reservoir to the seepage cup. The second connector was attached to a tube which extended above the water level in the canal. This second tube was used to observe the water pressure in the seepage cup. The meters had two basic designs (Figure 1). Type 1 had both connectors on the closed end of the bucket. Type 2 had the presure connector on the end of the bucket and the water inlet on the side. The type 2 meter was used only in canal 3.

TABLE II

IDENTIFICATIONS AND DIMENSIONS OF THE SELECTED CANALS

Canal Number	Soil Type	Length of Canal (m)	Average Width of Water (m)	Average Wetted Perimeter (m)	Average Cross-Section Area (m^2)
1	clay loam	1340	10.1	11.2	13.6
2	clay loam	650	10.4	11.3	12.7
3	clay loam	210	3.0	3.3	1.2
4	fine sandy loam	500	7.4	8.2	7.1

Seepage cups were installed in the bottom and on the sides of the canals when the water started filling the canals. The seepage cups were filled with water and then placed carefully into the ground by forcing them first by hand and then by stepping on them (Kraatz, 1977). Seepage cups were installed at 61 m intervals in canals 1 and 2, and at 20 m intervals in canal 3. Seepage cups were also installed on the sides of canals 1 and 2 at 183 m intervals at two elevations. The meters installed in the sides of the canal were approximately 1/3 and 2/3 the distance from the canal bottom to the water surface. When the water reached its normal elevation in the canal, plastic bottles were filled with six liters of water and were connected to the water tubes through a rubber stopper. The bottles were left to float on the water surface in the canal with the stopper positioned downward. The pressure tubes showed the pressure on the inside of the meter differed from that on

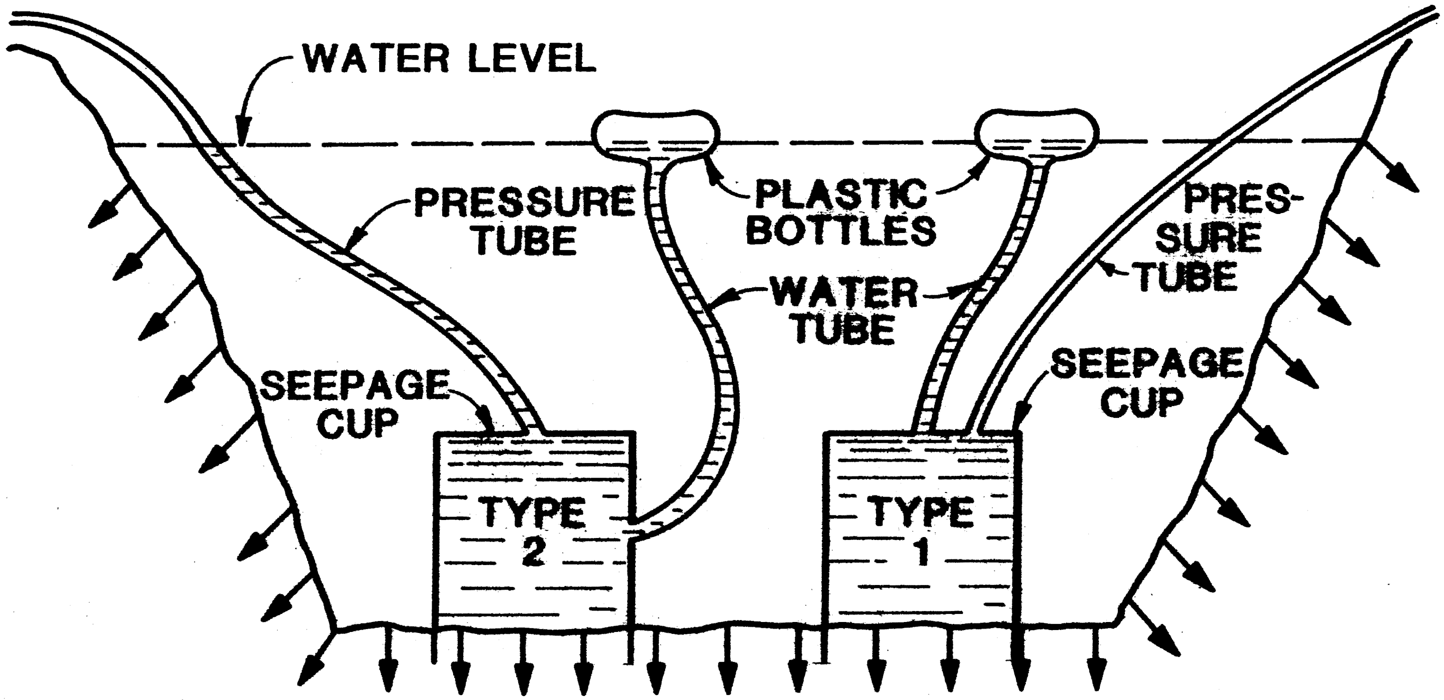

Fig. 1. Diagram of Types 1 and 2 Seepage Meters
Used in the Irrigation Canals

the outside by less than $\pm$ 0.5 cm of water. This variation occurred as time passed for each meter. No explanation for these small differences was apparent. After approximately 12 hours, the amount of water remaining in the bottle was measured. The difference between the volume of water placed in the bottle and the volume left after the period of measurement was the amount of water that had seeped through the soil under the seepage cups. After measuring the amount of water left in the bottles, the bottles were filled with water and the seepage measurements were repeated. Five measurements of seepage rate were taken from each seepage meter in canals 1 and 2, and four measurements were taken in canal 3. Attempts were made to measure the seepage rate in canal 4, but the canal was too large for ponding and the current in the canal was too swift for the placement of seepage meters.

Seepage was measured in canal 3 by ponding and seepage meter methods. A dam made of board covered with plastic sheets was constructed at the downstream end of the canal. The board was supported by existing canal structures, and the edges of the plastic were covered with soil and bricks to prevent leakage. After having completed the downstream dam, water was allowed to fill the canal by opening the gate from the main canal. When the canal was full, the gate was closed and another dam was constructed at the upstream end of the canal to prevent water from entering the canal. A water stage recorder mounted in a steel stilling well was used to monitor the elevation of water in the canal continuously. Seepage meters were installed in the canal bottom. At each site, both type 1 and type 2 seepage meters were used. Seepage rate in canal 3 was measured four times by seepage meters and three times by ponding.

Seepage rate per unit length of canal can be obtained by using the following equation:

$$V = i \times D \qquad (1)$$

where V is seepage rate/unit length of canal, i is the average seepage rate, and D is the width of water in the canal. The average seepage volume/unit time/unit area of wetted surface, R, is given by

$$R = V/L \qquad (2)$$

where V is seepage rate/unit length of canal, and L is the average wetted perimeter of the canal.

Infiltration Rate

Infiltration rate measurements were made in two sections of the irrigation canal by using the dual-ring method. The larger ring was 59 cm in diameter, and the smaller ring was 46 cm in diameter. The small ring was installed inside the larger one; the depth of installation was about 5 cm. The outer ring was filled with water first to ensure that there was no leaking from one ring to the other. The inner ring was filled next with water to the same level as the outer ring to equalize possible head difference between the two. The height of water in the inner ring was measured each hour. The infiltration process was maintained for seven to 12 hours. The rings were filled with water every one or two hours. Three infiltration rate measurements were taken in canal 2. The measurements were made at 45, 340, and 540 m from the beginning of the section. Infiltration rates were measured at two locations of canal 4 at 70 and 250 m from the beginning of the canal.

CHAPTER IV

RESULTS AND DISCUSSION

Seepage Rates

Table III shows the measured seepage rates for canal 1. Five successive measurements were made at each location. Seepage as measured by the seepage meter was highly variable. Also, more than 45% of all measurements resulted in negative seepage rates, i.e., the amount of water in the plastic bag was greater at the end of the 12-hour measurement period than at the beginning. More than 34% of all the measurements on the canal bottom resulted in negative seepage rates, and more than 63% on the canal sides resulted in negative seepage rates. The mean seepage rate from the positive measurements in canal 1 was 3.2 cm/day. Table IV provides similar results for canal 2. Here, 30% of the measurements resulted in negative seepage rates, 16% of the measurements on the canal bottom were negative, and 45% of those on the canal sides were negative. The mean seepage rate from the positive measurements was 2.1 cm/day. Table V includes the measured seepage rates for canal 3 for both types of seepage meters. Four successive measurements were made at each location. Fifty-six percent of the measurements resulted in negative seepage rates for type 1, and 42% resulted in negative seepage rates for type 2. Again, the variability of seepage rates at the same location was very high for both types of seepage meters. In this canal, all of the seepage cups were installed

TABLE III

SEEPAGE RATES (cm/day) FOR CANAL 1 MEASURED BY TYPE 1 SEEPAGE METERS

Seepage Meter No.	Observation 1	2	3	4	5
1	4.06	2.47	2.11	1.56	0.84
2	1.59	6.04	7.60	5.16	5.55
3**	3.74	5.91	2.76	2.05	<0
3*	4.00	1.43	2.44	<0	.97
3	2.34	<0	1.88	.71	2.01
4	2.89	2.83	2.08	1.10	<0
5	<0	8.77	.75	0	<0
6**	4.38	5.49	2.14	<0	1.04
6*	<0	<0	<0	<0	<0
6	.55	<0	<0	.49	<0
7	1.40	12.67	12.18	18.84	16.35
8	<0	5.62	.62	1.30	1.88
9**	<0	<0	<0	<0	<0
9*	2.18	2.79	<0	<0	<0
9	3.12	2.34	1.72	1.46	1.79
10	1.01	8.90	<0	.94	.78
11	<0	<0	<0	<0	<0
12**	5.49	4.74	<0	<0	<0
12*	3.25	5.39	2.37	2.44	.75
12	8.44	5.59	3.02	<0	<0
13	1.43	<0	6.82	4.42	5.94
14	1.62	1.07	<0	5.46	9.42
15**	<0	<0	<0	<0	<0
15*	<0	<0	<0	<0	<0
15	1.75	2.73	2.27	1.85	2.76
16	<0	<0	3.83	1.62	.71
17	<0	<0	<0	<0	<0
18**	<0	<0	<0	<0	<0
18*	<0	<0	<0	<0	<0
18	<0	<0	<0	<0	<0
19	<0	.65	<0	<0	<0
20	.16	.75	1.04	1.95	.16
21**	<0	<0	<0	<0	<0
21*	.88	6.17	1.79	2.50	1.88
21	<0	<0	5.65	3.28	4.55
22	<0	1.53	<0	0.91	<0
23	1.01	1.72	.68	1.33	1.95

*Seepage meter on side of canal (approx. 1/3 from bottom).
**Seepage meter on side of canal (approx. 2/3 from bottom).

TABLE IV

SEEPAGE RATES (cm/day) FOR CANAL 2 MEASURED BY TYPE 1 SEEPAGE METERS

Seepage Meter No.	Observation				
	1	2	3	4	5
1**	.39	1.33	.64	<0	1.01
1*	.97	1.69	1.46	7.41	5.07
1	.94	.84	1.43	2.21	4.38
2	<0	.91	<0	.91	1.46
3	.94	1.46	1.46	.75	1.79
4**	<0	<0	<0	<0	<0
4*	<0	3.67	<0	.45	5.20
4	<0	.49	<0	<0	2.96
5	3.02	.65	<0	<0	3.25
6	1.53	1.79	.62	.55	.78
7**	<0	<0	<0	<0	5.23
7*	2.4	2.31	2.27	1.33	7.63
7	8.93	10.62	.55	.62	3.12
8	.81	1.23	<0	.97	1.69
9	.39	1.01	<0	.49	3.61
10**	<0	<0	<0	<0	<0
10*	.78	.58	<0	1.59	1.46
10	.84	.58	.52	.52	1.53

*Seepage meter on side of canal (approx. 1/3 from bottom).
**Seepage meter on side of canal (approx. 2/3 from bottom).

TABLE V

SEEPAGE RATES (cm/day) FOR CANAL 3 MEASURED BY TYPES 1 AND 2 SEEPAGE METERS

Location	Observation 1	2	3	4
1	<0	<0	<0	<0
1*	.58	<0	<0	<0
2	1.40	<0	<0	1.56
2*	1.66	<0	1.04	<0
3	<0	<0	<0	1.49
3*	5.23	.78	<0	<0
4	.39	2.08	<0	1.56
4*	7.44	<0	13.97	.71
5	2.70	-	5.00	<0
5*	.94	<0	4.87	.65
6	.52	-	.91	<0
6*	.55	-	5.52	<0
7	.36	-	<0	<0
7*	1.07	-	3.77	<0

*Seepage rate measured with type 2 seepage meter. Others measured with type 1 meter.

on the canal bottom, and no velocity interruption occurred during measurement because the canal was sealed off by two dams to measure seepage by the ponding method. The mean seepage rate was 1.66 cm/day for type 1 meters and 2.9 cm/day for type 2 meters.

The large variability in measured seepage rates and the excessive number of negative seepage rate estimates were of great concern. Numerous attempts were made to determine the source of the problems with the seepage meters. One source considered was entrapped air. Air bubbles at the top of the seepage cups were thought to possibly prevent water from flowing from the plastic bottles to the seepage cups. Type 2 seepage meters were designed to eliminate this problem since water entered the sides of the type 2 seepage meters where air bubbles could not interfere. Also, all of the seepage cups were filled completely with water before being pressed into the ground. Air in the water tubes was also removed before beginning the measurements. The results for type 2 meters in canal 3 were not substantially improved over the results for type 1 meters. This suggests that air bubbles were not the cause of the highly variable results.

Leakage from the bottom of the seepage cups due to imperfect installation or excessive disturbance of the soil was also considered. Great care was taken in installing the seepage cups. They were gently forced into the ground by hand and then by stepping on them, as advocated by Kraatz (1977). The lip on the bucket on one seepage meter was removed so the edge was very sharp and thin. This should have reduced the soil disturbance. However, the results for that meter were not improved. Negative seepage rates were measured when the water in the bottle increased rather than decreased during the period of measurement. Water movement from the seepage meters to the plastic bottle can occur only when the pressure on the water within the seepage meter is less than in the surrounding canal. The pressure tubes on the meters showed that the pressure on the inside of the meter differed from that on the outside by less than ± 0.5 cm of water. This pressure fluctuated slowly with time, but no reason for the fluctuation could be found.

These efforts to determine and eliminate the sources of error in the seepage meter measurements were not successful. Additional uncertainty about the validity of the seepage meter results arose due to the poor agreement between the seepage meters and ponding measurements in canal 3, as described below.

Figure 2 shows the seepage losses as a function of time in canal 3 as measured by the ponding method. The measurements were repeated three times. The seepage rates for experiments 1, 2, and 3 were 13.3, 8.6, and 7.5 cm/day, respectively. Previous similar experiments conducted by Nofziger, Rice, and Mishu (1979) to measure seepage rates in other canals by ponding did not show comparable decreases. The decrease in seepage rate may have been caused by sedimentation of soil particles on canal sides and bottom. Surface soil was carried into the canal by the runoff from an intense rainstorm which interrupted experiment 1. The small differences in measured seepage rates between experiments 2 and 3 are comparable to those differences observed by Nofziger, Rice, and Mishu (1979). If the lower seepage rates observed in experiments 2 and 3 were due to sedimentation of soil particles, this suggests that these rates underestimate the normal seepage rate and that the results from experiment 1 may be the better estimate. The magnitude of seepage rates for canal 3 from experiment 1 was comparable to those

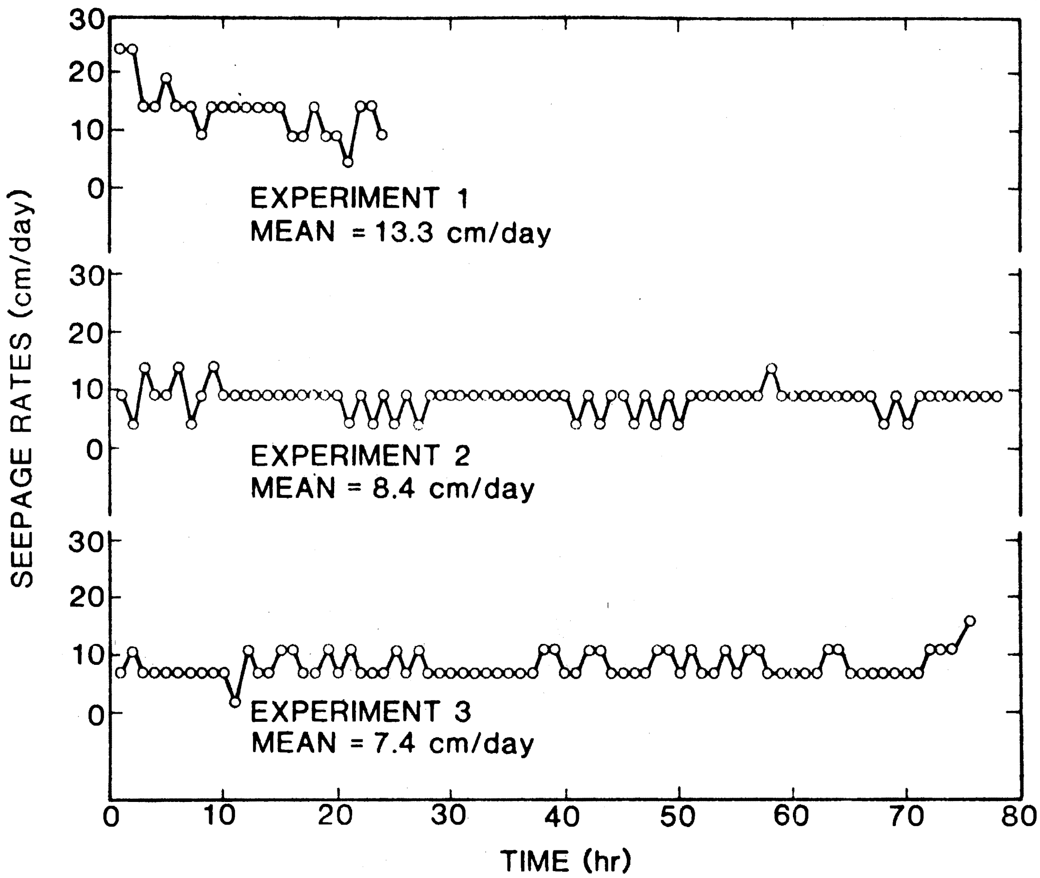

Fig. 2. Seepage Rates Measured by the Ponding Method in Canal 3 as a Function of Time

previously measured by Nofziger, Rice, and Mishu (1979) for similar canals in the area.

The seepage rates measured by ponding in canal 3 were more than five times those obtained by seepage meter methods. These results created additional uncertainty on the validity of the seepage meter measurements.

Estimating Seepage Rates for Large Canals

Because seepage meter measurements were apparently not reliable, seepage losses from the main canals were estimated. The assumption was made that the average seepage volume per unit of time per unit area of the wetted surface of canals 1 and 2 was the same as that for canal 3. If true, then the seepage rate per unit length of canals 1 and 2 could be calculated. Previous experiments by Nofziger, Rice, and Mishu (1979) indicated that the average seepage volume per unit of time per unit area of wetted surface for a sandy loam canal as measured by the ponding method was 26.4 cm^3/cm^2/day. This seepage rate was assumed applicable for canal 4. Table VI shows the average seepage rates as measured by seepage meter and ponding methods for canal 3 and estimated seepage rates for canals 1, 2, and 4.

Infiltration Rate

Figures 3 and 4 show infiltration rates as functions of time for canals 2 and 4, respectively. The average infiltration rates into the clay loam soil of canal 2 were 24.6, 69.3, and 78 cm/day at locations 45, 340, and 540 m from the beginning of the canal. The infiltration rates in the sandy loam soil of canal 4 were 89.5 and 32.2 cm/day at

TABLE VI

AVERAGE SEEPAGE RATES AS MEASURED BY SEEPAGE METER AND PONDING METHODS FOR SMALL CANALS AND ESTIMATED SEEPAGE RATES FOR LARGE CANALS

Canal Number	Average Width of Canal (cm)	Average Wetted Perimeter (cm)	Average Seepage Rate-by Seepage Meters (cm/day)	Average Seepage Rate-by Ponding (cm/day)	Average Seepage Volume/ Unit Area of Wetted Surface-by Seepage Meters ($cm^3/cm^2/day$)	Average Seepage Volume/ Unit Time per Unit Area of Wetted Surface-by Ponding ($cm^3/cm^2/day$)	Seepage Rate/ Unit Length of Canal-by Seepage Meter ($cm^3/day/cm$)	Seepage Rate Unit Length of Canal-by Ponding ($cm^3/day/cm$)
1	1006	1118	3.2	13.4*	2.9	12.1*	3220	13,400*
2	1038	1132	2.1	13.2*	1.9	12.1*	2180	13,800*
3	300	330	2.3**	13.3	2.1**	12.1	690**	4,000
4	743	819	-	29.1*	-	26.4	-	21,600*

*Estimated seepage rate.
**Average seepage rate from type 1 and t-pe 2 seepage meters.

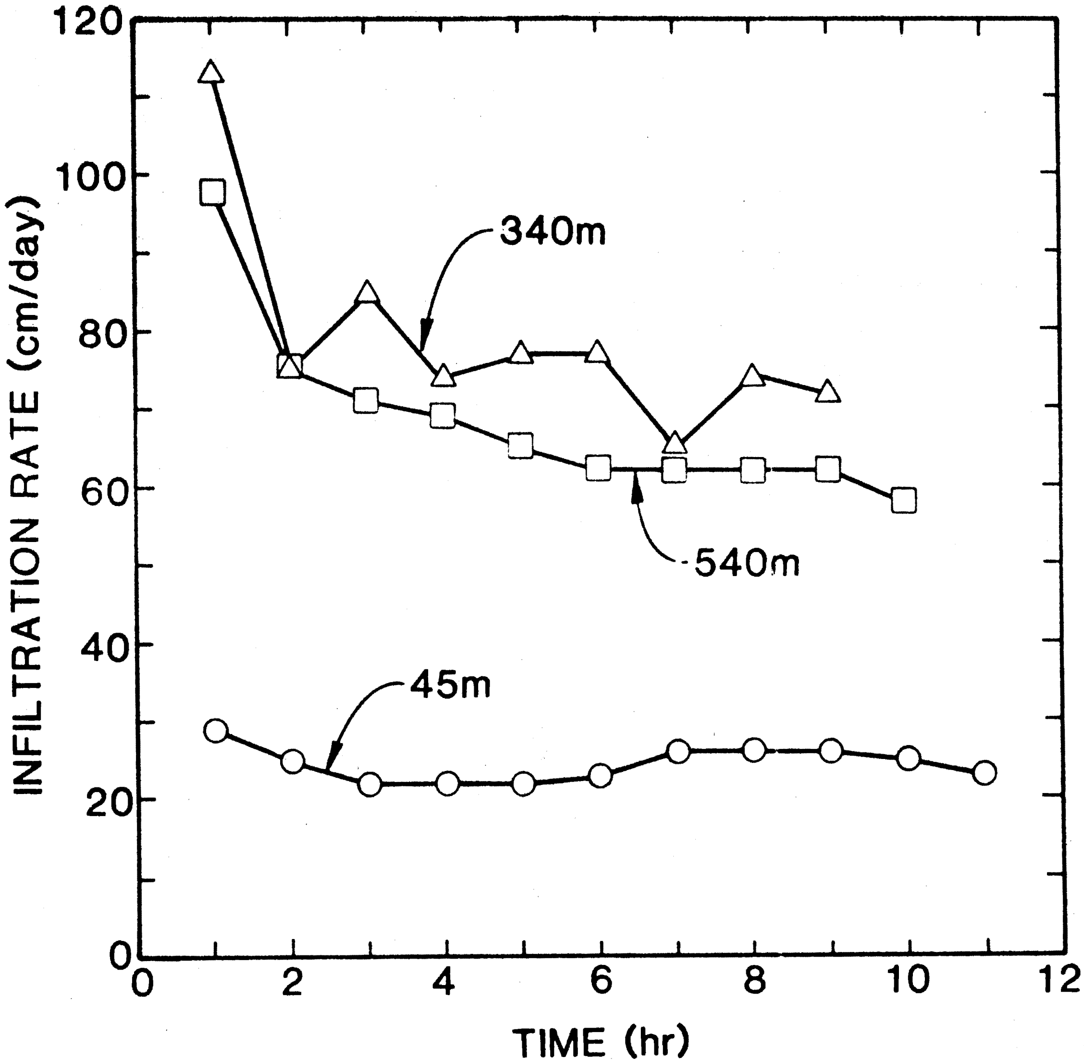

Fig. 3. Infiltration Rates at Three Specific Locations of Canal 2 as a Function of Time

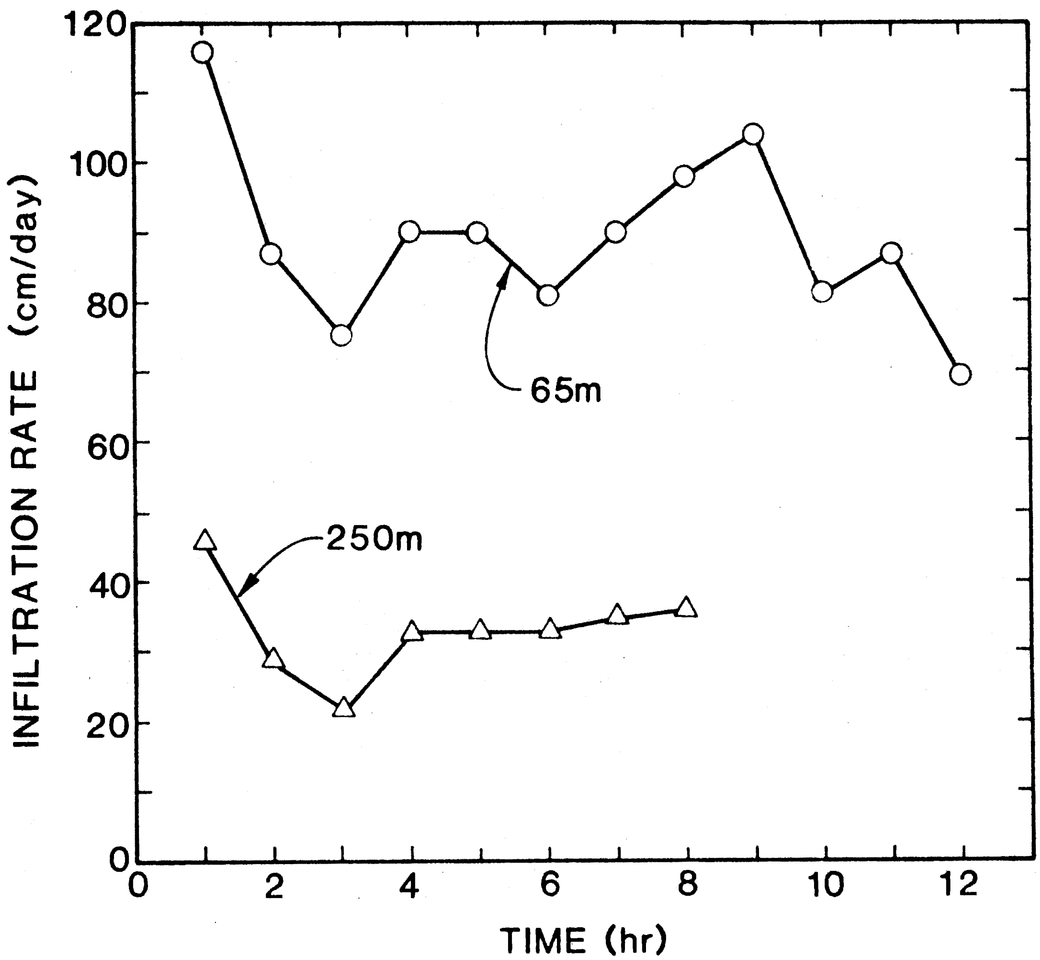

Fig. 4. Infiltration Rates at two Specific Locations of Canal 4 as a Function of Time

locations 65 and 250 m from the beginning of the canal, respectively. These infiltration rates represent the seepage rates during the first few hours after filling the canal. The seepage rates in canals 2 and 4 as estimated from the ponding method were 13.3 and 29.1 cm/day, respectively. This means that the initial rate of water loss was one to five times that of the seepage rate measured toward the end of the irrigation season.

Infiltration rates normally decrease with time (Hillel, 1971), but the experiments on locations 45 and 340 m in Figure 3 and both experiments in Figure 4 show that infiltration rates sometimes decrease and sometimes increase. The uncertainty in these measurements should not exceed 0.2 cm/hr. Thus, the changes do not appear to be due to only experimental error. Soil stratification may be another explanation. Results obtained in these experiments are qualitatively similar to those obtained by Miller and Gardner (1962) due to interruption of water movement by a coarser textured layer. Experiments at 45 m in figure 3 and at 250 m in Figure 4 show that the initial infiltration rates were lower than in the other experiments. This may have been due to compacted soil surface or the profile covered by a surface crust of lower conductivity which lowered infiltration rate (Edwards and Larson, 1969).

CHAPTER V

SUMMARY

Seepage rates were measured using the seepage meter method in two sections of the main irrigation canal in a small canal in the Altus, Oklahoma, area. Using this technique, the observed seepage rates were highly variable at the same location; numerous measurements resulted in negative seepage rate estimates. The positive estimates also were much lower than the seepage rates obtained by the ponding method. These results indicate that the seepage meter method does not accurately measure seepage.

To determine the sources of the problems with the seepage meter, careful and repeated measurements were taken. These efforts showed that entrapped air at the top of the seepage cup, entrapped air in the water tube, leakage from the bottom of seepage cups due to imperfect installation, and excessive disturbance of the soil were not the major problems with the seepage meter. Also, the presssure on the inside of the meter differed from that on the outside by less than $\pm$ 0.5 cm of water. This pressure fluctuated with time, but no reason for the fluctuation could be found.

Seepage rates were estimated in two sections of the main canal and in the sandy canal by measuring the seepage rate in smaller canals with the same soil type by the ponding method and using these data to predict performance of main canals.

Infiltration rates were measured in the main canal and in the sandy canal by using the dual-ring method. Initial rates of water loss were much greater than those measured at the end of the irrigation season.

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APPENDIX A

CANAL LOCATIONS

Canal 1: Location: NW 1/4, SW 1/4, Sec. 32, T. 2N, R 20W, Jackson County.
Soil: Tillman-Hollister clay loam (Typic and Pachic Paleustolls). Canal 1 runs north and south at east edge of this area.

Canals 2 and 3: Location: NE 1/4, Sec. 6, T. 1N, R. 20W, Jackson County.
Soil: Tillman-Hollister clay loam (Typic and Pachic Paleustolls). Canal 2 runs north and south at east edge of this area. Canal 3 runs north and south in northeast corner of this section. Results shown in Figs. 2 and 3 are from this area.

Canal 4: Location: SE 1/4, Sec. 19, T. 3N, R. 20W, Jackson County.
Soil: Miles fine sandy loam Udic Paleustalfs). Canal 4 runs east and west at north edge of this section. Results shown in Fig. 4 are from this area.

APPENDIX B

DESCRIPTION OF SOILS

Hollister Clay Loam (Pachic Paleustolls)

A_{1p} 0 to 5 inches, grayish brown (10YR, 5/2, dry; 3.2, moist) clay loam; weak, granular structure; hard when dry, firm when moist; noncalcareous (pH 7.5); abrupt boundary.

A_1 5 to 9 inches, very dark gray (10YR, 3/2, dry; 2/2, joist) clay loam; weak granular structure; hard when dry, firm when moist; many fine pores; peds have a weak shine; noncalcareous (pH 5.5); gradual boundary.

B_2 9 to 28 inches, very dark gray (10YR, 3/1, dry; 2/2, moist) clay; moderate, medium, subangular blocky structure becoming blocky at 16 inches; very hard when dry, firm to very firm when moist; clay skins apparent; noncalcareous to 20 inches (pH 7.5); gradual boundary.

B_2 28 to 36 inches, gray (10YR, 5/1, dry; 4/1, moist) clay; weak, blocky structure; very hard when dry, very firm when moist; few whitish spots of soft calcium carbonate; calcareous; gradual boundary.

C_{ca} 36 to 44 inches, gray (10YR, 5/1, dry; 4/1, moist) clay; weak, blocky structure; very hard when dry, very firm when moist; more compact than layer above; mixture of soft and hard concretions of calcium carbonate; strongly calcareous; gradual boundary.

44 to 50 inches +, gray (10YR, 5/1, dry; 5/2, moist) clay, grading to reddish-brown clay. This is apparently redbed residuum.

From Bailey and Graft (1961).

Tillman Clay Loam (Typic Paleustolls)

A_1 0 to 10 inches, reddish-brown (5YR, 4/3, dry; 3/3.5, moist) clay loam becoming slightly darker in color below plow depth; slightly crusted surface; weak granular structure; hard when dry, firm when moist; noncalcareous (pH 7.5); clear boundary.

B_2 10 to 28 inches, reddish-brown (5YR, 4/3, dry; 3/2, moist) light clay that is slightly lighter in color when crushed; moderate, very fine, blocky structure; very hard when dry, very firm when moist; clay skins apparent, but not pronounced; few small, black concretions; noncalcareous (pH 8.0); gradual boundary.

C_{ca} 28 to 50 inches, reddish-brown (5YR, 3/4, dry; 3/6, moist) clay; massive (structureless); very hard when dry, very firm when moist; many soft concretions of calcium carbonate; soil mass calcareous; gradual boundary.

C 50 to 60 inches, yellowish-red (5YR, 4/6, dry; 3/6, moist) clay containing less calcium carbonate concretions than above.

From Bailey and Graft (1961).

Miles Fine Sandy Loam (Udic Paleustalfs)

A_{1_p} 0 to 6 inches, brown (7.5Yr, 5/4, dry; 4/4, moist) fine sandy loam; friable when moist; noncalcareous (pH 6.7); abrupt boundary.

A_1 6 to 10 inches, dark-brown (7.5YR, 4/2, dry; 3/2, moist) fine sandy loam; moderate, medium, granular structure; friable when moist; many wormcasts; noncalcareous (pH 6.7); gradual boundary.

B_2 10 to 36 inches, reddish-brown (5YR, 4/4, dry; 3/4, moist) sandy clay loam; compound, coarse prismatic, and moderate, medium, granular structure; hard when dry; friable when moist; outside of peds have slight, dark coating; many open pores and wormcasts; moderately permeable; noncalcareous (pH 7.0); gradual boundary.

B_2 36 to 54 inches, yellowish-red (5YR, 5/6, dry; 4/6, moist) sandy clay loam that contains less clay and is slightly more friable than the horizon above; same structure as overlying horizon; hard when dry; noncalcareous (pH 7.0); gradual boundary.

C 54 to 72 inches +, yellowish-red (5YR, 5/8, dry; 4/8, moist) fine sandy loam; soft when dry, very friable when moist; noncalcareous (pH 7.5).

From Bailey and Graft (1961).

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