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ESTIMATING SEEPAGE LOSSES FROM CANAL SYSTEMS

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INTRODUCTION

Seepage and operational losses from distribution systems are continuing problems for designers and managers of irrigation districts and for water users. The designer must provide sufficient capacity in the canals to allow for these losses, and the managers must divert extra water into parts of the system to assure ample flow to the lower reaches of all laterals. The water users must provide for ample storage to offset seepage losses. The managers also have to deal with more complex legal and technical problems that arise if seepage losses cause high water tables in fields adjacent to the canal.

As demands increase on all the water supplies of the West, regional and state resource management agencies are looking critically at the large volumes of water diverted by agriculture, especially when these volumes are much larger than the amounts used in evapotranspiration. These agencies need guidelines for more accurately determining reasonable water diversions to irrigated agriculture. Some information is available. Hart (6) estimated seepage losses from canals in several of the soils found in southern Idaho (Table 1), but such information for other areas is not available in the literature. This paper presents a simplified method that engineers and resource planners can use to estimate seepage losses from new or existing canal systems.

METHODS OF SEEPAGE MEASUREMENT

Four principal methods have been used to estimate or measure seepage and operational losses from distribution systems. Normally, estimates are made with an "inflow-outflow" approach by using the records of diversion and delivery for the district. This approach gives an estimate of the total seasonal operational losses, which include canal seepage, canal spill, generous deliveries, and gains

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or losses from inaccurate measurements. Inflow-outflow estimates usually express the loss as a percentage of the total flow into the entire system or large parts of it. Expressed in this manner, it is difficult to relate the loss in one system to those in other systems. Published losses based on a percentage of total flow seldom include data on the size of canals, soil types, or length of irrigation

TABLE 1.—Loss Rates from Canals in Southern Idaho* (6)

Type of soil (1)	Loss rate, in feet per day (meters per day) (2)
Medium clay loam	0.5-1.5 (0.15-0.46)
Impervious clay	0.5 (0.15)
Medium soils	1.0 (0.3)
Somewhat pervious soils	1.5-2.0 (0.46-0.61)
Gravel (depending on porosity)	2.5-5.0 (0.76-1.52)

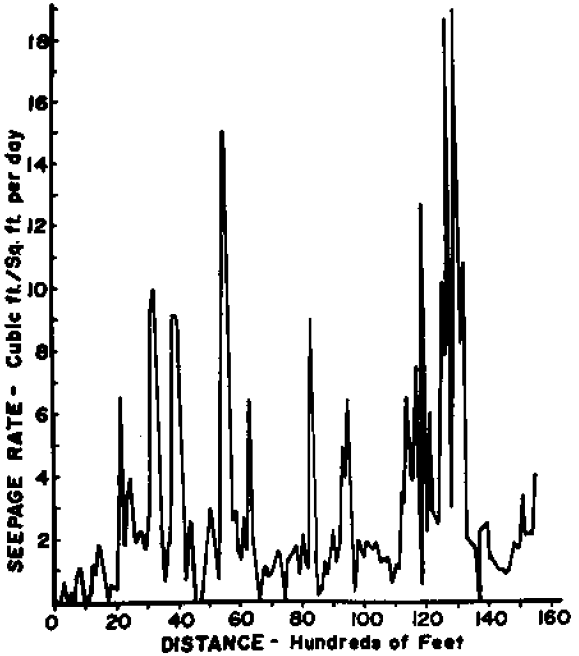

FIG. 1.—Variations of Seepage Rates Measured at 100-ft (30-m) Intervals along Center Line of Canal in Sandy Loam Soil near Rupert, Idaho, July 1970 [Average Rate = 2.58 ft/day (0.79 m/day)]

season. With demands on water supplies increasing, it is important that losses of various districts be compared and the magnitude of each aspect of operational losses in parts of the systems be identified to aid in deciding priorities for making improvements.

The second method is a refinement of the first in that it is based on actual inflow-outflow measurements made over 1 hr or 2 hr on specified reaches of a canal or lateral. This method eliminates some of the undefined variables of the first method, but the inaccuracy of water measurement techniques continues to be a major problem, especially on the older irrigation systems. As a result, the losses obtained by this method are often based on total flow measurements by current metering natural streams and canal sections, and the deliveries are measured by current metering or by flow over weirs or structures with questionable accuracies. A small change in the canal water level during measurement of discharges can cause errors large enough to mask part or all of the losses. This is particularly true if the losses are less than 10% of the total flow in the canal. However, this type of measurement has merit on canals with high losses and where long reaches are being tested so that the seepage loss is a significant percentage of the total flow.

A third method of seepage measurement is to pond water in the canal to the approximate operating depth and then record or periodically measure the drop in the water surface with time. This is the most accurate method, but large canals must be taken out of operation for about 2 weeks to make the measurements. Measurements must be made on main canals either before or after the irrigation season, and the seepage rate then probably differs from the seasonal average. Inasmuch as reservoirs and lakes usually have much lower seepage losses than canals, the canal seepage rate measured by ponding may be less than it would be when influenced by canal currents near the bottom. If the ponded section is long, the average seepage rate measured by ponding will not identify any localized high loss zones within the ponded section.

A fourth method of measuring canal seepage losses consists of making spot measurements with a small meter that measures seepage through a small area. There are several variations in seepage meter design. Two models have been described by Robinson and Rohwer (11). Because seepage rates vary widely from point to point, many measurements must be made throughout the length of a canal to achieve an acceptable average value. Brockway and Worstell (3) presented a method to statistically estimate the number of seepage meter measurements required in a given reach of canal to approach the true value. The seepage meter can be used in many operating canals, which extends the time during which the seepage losses can be measured. This method also will identify localized high-loss reaches. However, it cannot be used in canals with rocky or rubbly perimeters, nor in canals with flow velocities higher than about 2 ft (0.6 m)/sec.

Several variables affect the seepage according to location along the canal and the time of day or the time of the year that the measurement is made (3,11,20,22). Some of these are: (1) Water temperature changes; (2) siltation conditions; (3) bank storage changes; (4) soil chemicals; (5) water velocity; (6) microbiological activity; (7) irrigation of adjacent fields; and (8) water table fluctuations. For example, Robinson and Rohwer (11) found that seepage from experimental seepage rings fluctuated daily as much as 40% in sandy soils.

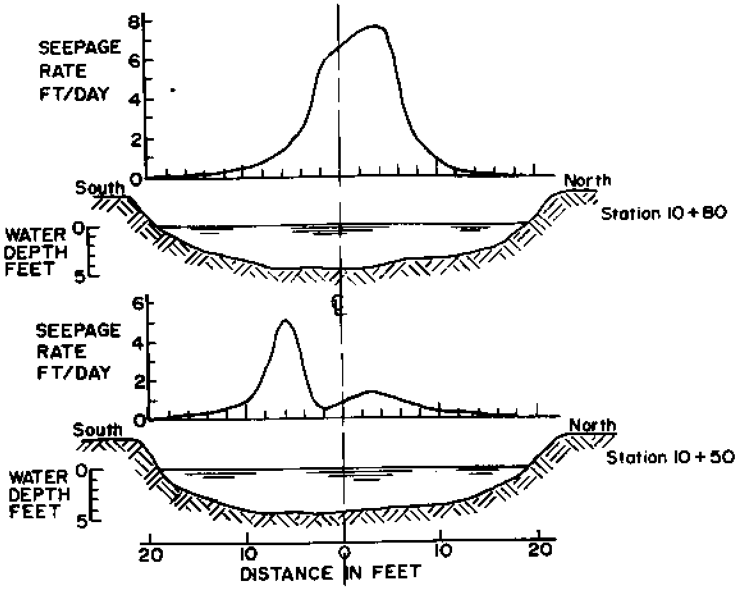

FIG. 2.—Variations in Seepage Rates Found Across Width of Large Canal

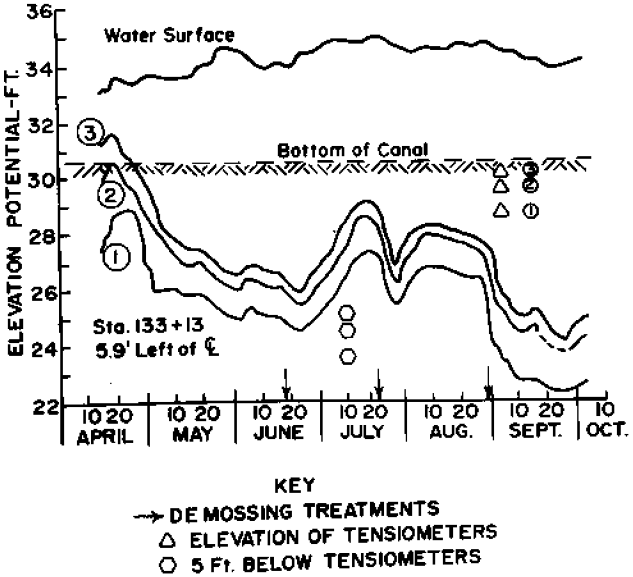

FIG. 3.—Changes in Hydraulic Potentials Found with Tensiometers Installed under Canal in Silt Loam Soil

Most of this was attributed to rather small water temperature changes that affected the gas pressures in the soil which, in turn, affected the soil hydraulic conductivity.

Fig. 1 shows the variations in seepage rates measured in July 1970 with a seepage meter at 100-ft (30-m) intervals along the center line of a canal in a sandy loam soil near Rupert, Idaho. Fig. 2 is an example of the variations in seepage rates that were measured across a large canal. Fig. 3 shows the seasonal variations in hydraulic head that were measured immediately beneath an operating canal during an irrigation season in southern Idaho. Water in the canal was about 5 ft (1.5 m) deep and measurements were made a few inches below the bottom of the canal. At a depth of 3 in. (76 mm) below the bottom, soil moisture tensions gradually increased to a maximum of about 5 ft (1.5 m) of tension at the end of the season. This indicated that seepage from this canal in a Portneuf silt loam soil decreased throughout most of the season, because a thin sealing layer formed at the soil-water interface. The fluctuations in hydraulic head may have been caused by xylene treatments to remove moss from the canal. This treatment could have reduced the effectiveness of the bottom seal.

Since many variables affect seepage rates, it is unusual to measure a consistent seepage value for a given reach of a canal. The objective of this study was to determine an approximate range of seepage losses as related to soil texture and canal size.

PROCEDURE

A literature survey yielded 765 seepage measurements made by ponding, or by seepage meter, where seepage was recorded in (or could be converted to) cubic feet per square foot per day, or feet per day as a "unit seepage rate" (1,2,4,5,8,9,10,12,13,14,15,16,17,18,19,20,21). These data were from tests in 15 states in the western United States over more than 40 yr, with much of the work done of the last 20 yr. Some recent unpublished data from Idaho and Washington also were included. Minimal soil texture and profile information was reported in 85% of the seepage measurements. Data on lined canals were included when tests had been made to determine the effectiveness and durability of different types of linings. When the same reach of a lined canal was retested for several years, the seepage rate measured after 3 yr-4 yr of service was considered to be the representative rate for that lining. This was done to allow for the initial rapid aging or deterioration that often occurred in the first 2 yr-3 yr.

The tabulated information included the following data, if available: (1) Location of test by state, district, canal, and location along the canal; (2) year test was made; (3) length of reach tested; (4) width and depth of canal; (5) topsoil texture; (6) subsurface soil and other subsurface conditions; (7) unit seepage rate; (8) type of lining, if any; and (9) type of test (ponding, seepage meter).

The soils were grouped into four broad textural classifications based on the limited topsoil descriptions given. These classifications were: clayey soils, silty soils, loamy soils, and sandy soils. When the soil texture was not reported, that test was placed in an "unspecified" category. A test by the seepage meter technique was tabulated when there were at least several individual locations

TABLE 2.—Seepage Rates of General Soil Groups

General soil group (1)	Ponding Tests: Number of tests (2)	Ponding Tests: Average rate, in feet per day (meters per day) (3)	Seepage Meter Tests: Number of tests (4)	Seepage Meter Tests: Average rate, in feet per day (meters per day) (5)
Clayey	20	0.23 (0.07)	3	0.65 (0.20)
Silty	120	0.80 (0.24)	16	0.55 (0.17)
Loamy	196	0.94 (0.29)	11	0.85 (0.26)
Sandy	77	1.56 (0.48)	28	1.91 (0.58)
Unspecified	55	1.01 (0.31)	30	1.13 (0.35)

TABLE 3.—Seepage from Lined Canals (Ponded Seepage)

Lining type (1)	Number of tests (2)	Average seepage rate, in feet per day (meters per day) (3)	Range, in feet per day (meters per day) (4)
Concrete	11	0.24 (0.07)	0.03–0.96 (0.009–0.29)
Compacted earth	45	0.17 (0.05)	0.01–0.95 (0.003–0.29)
Asphalt membrane	32	0.46 (0.14)	0.01–3.0 (0.003–0.92)
Soil cement	5	0.08 (0.02)	0.03–0.20 (0.009–0.06)
Chemical sealant	12	1.79 (0.55)	0.32–8.3 (0.1–2.53)
Sediment seal	10	0.78 (0.24)	0.39–1.3 (0.12–0.4)
Unlined—all soil types	468	0.99 (0.30)	0.01–17.6 (0.003–5.37)

tested within a reach of canal. There were only 20 ponding tests and three seepage meter tests of canals in clayey soils, probably because little loss was expected in such soils. Some of the data were reported in more than one publication; a special effort was made to avoid duplication. Sorting routines available on the Mark IV file Management System Program were applied to the data and standard statistical techniques were used for the analysis.

Results

Table 2 shows the average seepage rates for broad soil groups in unlined canals. Many more tests were made by ponding than by seepage meter. Table 3 summarizes the ponded seepage rates measured in lined and unlined canals. The histograms of Fig. 4 show that the ponded seepage rates for each soil group are skewed to the left. Moreover, even these values may be greater than the true average for all canals in the western United States because seepage measurements tend to be made on canals where high loss rates are suspected. The average unit seepage rate was found to be unrelated to pond (or canal) dimensions.

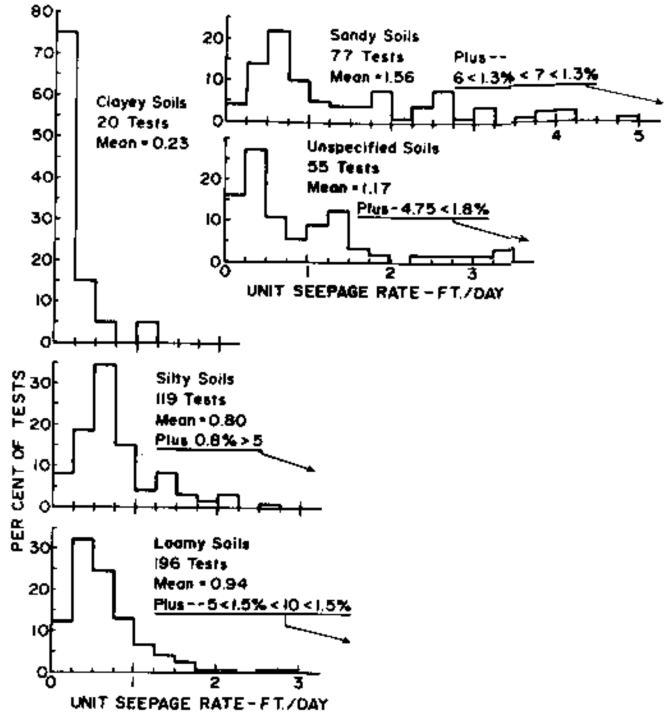

FIG. 4.—Histograms of Ponded Seepage Tests

Analysis of Results

Measurements with seepage meters compare favorably with measurements made by ponding (Table 2). Where many seepage meter tests are made along a reach of canal, their average value tend to be quite close to the value obtained by ponding (3).

The tests summarized in Table 3 indicate that most of the lined canals tested lost water at rates between about 0.1 ft/day and 1.0 ft/day (0.03 m/day and 0.3 m/day) after they have weathered and aged for a few years. The chemical sealant linings deteriorated more rapidly to even higher rates. However, average rates for the first four linings listed in Table 3 are one-fourth of the average rates of all the unlined canals. These data indicate that linings for seepage control would be most effective when installed in the high loss reaches of a canal, such as from station 2,000 ft-6,500 ft (610 m to 1,980 m), and from station 11,000 ft-13,500 ft (3,350 m-4,120 m) in the canal represented by Fig. 1.

Fig. 4 shows that seepage measurements do not follow a statistical "normal" distribution. In most ponding tests, seepage rates were in the lower ranges of less than 1 ft/day (0.3 m/day). Of the clayey soils tested, 90% seeped at rates below 0.5 ft/day (0.15 m/day); 76% of the silty soils, 82% of the loamy soils, 50% of the sands, and 59% of the unspecified soils seeped at rates of less than 1.0 ft/day (0.3 m/day). A few high values, especially in the loamy soils, caused the averages to be near 1.0 ft/day (0.3 m/day).

A seepage rate of 1.0 ft/day (0.3 m/day) corresponds to the basic irrigation intake rate of 0.5 in./hr (13 mm/hr) which is in the intake range for fine sandy loam soils in good condition or sandy soils that are puddled or crusted.

Col. 4 of Table 3 shows that the measured unit seepage rates for the unlined canals (all soil types) are highly variable. This is influenced by the natural variability of seepage previously mentioned, as well as the inadequately described soil textures and soil profiles. This natural variability indicates that, where high losses are suspected, seepage tests should be made on each specific reach of canal involved rather than using average rates. The values given in Cols. 3 and 5 of Tables 2 and 3 also indicate that average seepage rates range from 0.1 ft-1.9 ft (0.03 m-0.57 m) per day for any soil texture, lining type, and measurement method. The average unit seepage rates tend to be greater as soil texture grades from fine to coarse. Average rates for the western United States are similar to those cited by Hart (6) for southern Idaho as given in Table 1.

Because average seepage loss rates fall within a limited range, the average seepage losses from a canal system can be estimated reasonably accurately. To estimate the seepage loss from a system, the planner or resource manager will need a soils map, a map of the canal system, and a table of the approximate widths and lengths of the system's canals and laterals. For a given reach, the predominant soil texture can be determined and the associated average seepage rate determined from Col. 3 of Table 2. By using a set of curves as shown in Fig. 5, the flow loss in cubic feet per second per mile can be determined for different canal and lateral widths.

Better estimates of canal seepage rates provide input for economic analysis in evaluating the merits of canal lining. The following example is used to illustrate such an evaluation. A canal near Rupert, Idaho has the following characteristics: (1) Length, 2.94 miles (4.73 km); (2) water surface width, 14.0 ft (4.3 m); (3) slope, 0.00015 ft/ft; (4) seepage rate (sandy soil), 1.5 ft/day (0.48 m/day) (from Table 1); (5) design delivery, 30 cfs (0.85 m^3/s); and (6) flow lost to seepage, 4.38 cfs (0.124 m^3/s) approx 14.5% of design delivery.

The seepage loss would be reduced to about 0.56 cfs (0.016 m^3/s) or less if a lining were installed. This would be less than 2% of the design delivery rate and provide 3.8 cfs (0.11 m^3/s) of water for other applications during the 6-month irrigation season.

Lauritzen (7) cited costs of canal linings in the early 1960's as ranging between $0.85 and $3.02/sq yd ($1.02 and $3.65/$m^2$). (For this comparison, the effects of inflation and the offsetting effects of improved materials and installation equipment and techniques are not being considered.) One of the lower cost linings was heavy compacted earth at $1.00/sq yd ($1.20/m^2), and one of the more expensive linings was 3-in. (76-mm) thick unreinforced concrete at $3.00 sq yd (3.6/$m^2$). The cost of completely lining this canal using these figures would be $55,000 and $67,000 for earth and concrete linings, respectively. The cross section of the concrete-lined canal would be 18 sq ft (1.67 m^2), as compared to 28 sq ft (2.6 m^2) for the earth-lined canal, so that the concrete lining only costs 22% more than the earth lining. Which of the two linings one should select would also depend on other considerations, such as the availability of

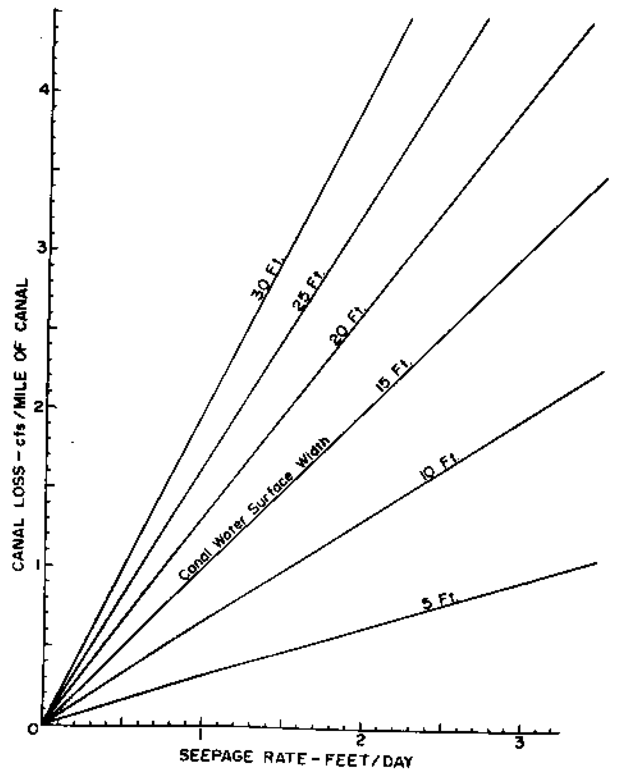

FIG. 5.—Chart to Aid in Estimating Flow Loss (Seepage Rate and Canal Dimensions Known)

a satisfactory soil for an earth lining and possible damage to the concrete lining from frost heaving or soil settlement.

The main reason for concern about seepage losses from this particular canal is the problem of delivering an adequate supply of water to the lower end of the canal during periods of high demand. If the water saved by the lining could not be used on other land in the district, it would be an expensive answer to this immediate, but only intermittent, problem. If the water could be sold locally or transferred elsewhere (with the costs amortized over 20 yr at 5%), the lining could be paid for simply by the water saved and sold at $192-$234/yr/cu ft/sec, depending on the type of lining installed. This is about 69-84% of the cost of irrigation water in the older districts of southern Idaho. Part of the area would also benefit from the lower water table that would result from the canal lining, and some of the lining cost might be assessed against this area. This example analysis indicates that lining this lateral would be profitable if the water saved could be sold elsewhere.

Conclusions

A review and summary of 765 seepage tests made in the western United States show that average unit seepage loss rates in cubic feet per square foot per day (or feet per day) range from 0.1 ft/day-2 ft/day (0.03 m/day 0.6 m/day). Seepage losses tend to increase as topsoil texture grades from clay toward sand, but losses vary widely within any one soil texture.

This information can help irrigation system planners and water resource managers make better estimates of the seepage losses from a canal system. Planning personnel can also use this approach in assessing the potential value of canal lining as compared to other improved water management practices.

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KEY WORDS: **Canals; Irrigation; Seepage; Seepage losses; Water loss;** Water resources; Water supply

ABSTRACT: Canal seepage rates for broad soil textural groups were evaluated by analyzing results of 765 tests made in the western United States. Seepage rates varied widely within each broad texture class, but the average rates for all the classes ranged from 0.2 ft to 2.0 ft (0.06 m/day to 0.6 m/day). Seepage rates were less than 1.0 ft (0.3 m) per day in most tests. Average rates were similar, whether measured by ponding or by seepage meter. No significant linear regression was found between canal dimensions and seepage rates within any one soil texture group. Average seepage rates for lined canals ranged from 0.1 ft to 1.0 ft (0.03 m to 0.3 m) per day. Irrigation system designers and resource planners will find these average rates helpful in estimating seepage losses for existing or planned systems. Average rates also will be helpful in evaluating alternative improvements in water management, such as canal-lining programs, modernizing measurement and delivery methods, and installing computer-controlled automatic regulation of diversions and deliveries.

REFERENCE: Worstell, Robert V., "Estimating Seepage Losses from Canal Systems," *Journal of the Irrigation and Drainage Division*, ASCE, Vol. 102, No. IR1, **Proc. Paper 11960**, March, 1976, pp. 137-147