FIELD EVALUATION OF SEEPAGE MEASUREMENT METHODS[1]

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INTRODUCTION

Irrigation project design, operation and maintenance, and canal-lining research and development require accurate and economical measurements of seepage rates. Drastically new methods for measuring seepage have not been developed, so existing field methods must be used. Each of these methods warrants an evaluation of its capabilities and limitations. This paper relates experiences with ponding tests, seepage meters, and inflow-outflow methods of measuring seepage from canals.

The results reported here represent the combined efforts of the University of Idaho Engineering Experiment Station, the Agricultural Research Service, and the U.S. Bureau of Reclamation.[3]

The study was performed in 1965 and 1966 on a 4.5-mile reach of the A and B Irrigation District Main Canal near Paul, Idaho. This canal is a part of the Minidoka Project of the U.S. Bureau of Reclamation. It is 25 to 30 feet wide with a gradient of about 0.5 feet per mile and flows at a depth of 5 to 5.5 feet during the irrigation season. Soils throughout the test reach are very uniform and consist almost entirely of Portneuf silt loam. A compacted, slightly cemented silt layer from 12 to 24 inches thick intersects the canal cross section throughout most of the the test reach. The flow system beneath the entire test reach is under tension gradients due to an impeding layer near the soil surface of the canal cross section.[4] Devices for recording water measurement were installed by the Bureau of Reclamation at the inlet and outlet and at all turnouts on the reach. A water budget for the irrigation season was maintained on this reach for 3 years, and the loss rates for 2-week periods were computed.

PONDING TESTS

Ponding tests were made on 1.5 miles of the test reach, 1 mile in the fall of 1965 and an additional ½ mile in the fall of 1966. The purpose of these tests was to measure actual canal seepage loss rates to use in determining water distribution efficiency on this part of the Minidoka Project, and to serve as standards for comparison with other seepage measurement techniques.

Plastic-covered earth dikes or plastic-covered wood bulkheads were used to isolate 0.5-mile-long ponds in each series of tests. Water stage recorders and hook gages were installed in corrugated metal stilling wells to measure water surface elevations. Recorders were located at each end of each pond to account for wind effects on the water surface elevations. In each of the ponding runs, the ponds were filled at least 12 hours before measuring the water surface drop began. Two runs were then performed, and the seepage rates on the second run were used as the operational seepage loss rates.

Ponding a 1-mile section of this canal with these techniques costs about $3,000.

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[4] Worstell, R. V. and Brockway, C. E. Estimating seasonal changes in irrigation canal seepage (1968). Paper presented at 1967 annual meeting of the Pacific Northwest Region of the Amer. Soc. Agri. Engin., Spokane, Wash. (Submitted in February 1968 for publication by A.S.A.E.)

The canal must be out of service for 10 to 14 days. This usually prohibits the performance of tests on main canals during the irrigation season. Tests early or late in the season in cold climates may require antifreeze in the stilling wells to prevent freezing. Regardless of these problems, ponding is still the standard method of measuring seepage losses. Whether it duplicates the operational seepage loss rates is open to question. The reasons why ponding seepage rates may vary from operational rates are discussed under the section "Seepage Meter and Ponding Test Results."

SEEPAGE-METER TESTS

Tests were run with a variable-head seepage meter developed by the Agricultural Research Service in the ponded reaches of the Main Canal before the ponding tests. In 1965, 71 tests were performed in one of the 0.5-mile ponds; and in 1966, 60 tests were performed in a 0.5-mile reach that was later ponded, and 26 tests in a 0.5-mile reach that could not be ponded because of a bulkhead failure. Tests were taken across the canal bottom at stations about 400 feet apart along the reach. Two groups of five measurements were made at each station.

Two men easily operated two ARS seepage meters in the 25- to 30-foot-wide canal. One man moved and inserted the meters in the canal, while the other recorded timed readings of manometers on the canal bank.[5] Two experienced men performed about 40 tests per day when seepage rates only were measured. The procedure for estimating hydraulic conductivity requires additional time, and about 20 tests per day were performed. The water level was maintained at about 22 inches at the centerline so that the meter could be inserted manually. A small flow was maintained to carry away sediments disturbed during the meter installation. Data were recorded on sheets with a punch-card format for processing with a digital computer.[6] Cost for obtaining a reasonable estimate of the seepage rate at a low water depth in this canal is about $300 per mile. When using this meter, water depths are limited to less than 2 feet, even though the operating depth of the canal may be much greater. A reasonable prediction of the seepage rate at the canal operating depth depends on the knowledge of the seepage flow system and soil conditions beneath the canal cross section.

SEEPAGE METER AND PONDING TESTS RESULTS

TABLE 1.—Comparison of seepage rates obtained by ponding and by seepage meter[1]

Item	1965	1966	Average 1965-1966
Average $\mathrm{C_L}$ water depth (inches)	22	20	21
Number of tests	71	60	66
Wetted area tested (percent)	.092	.086	.089
Ponded seepage rate (c.f.d.)	.50	.56	.53
Seepage meter rate (c.f.d.)	.68	.69	.68
Difference (c.f.d.)	.18	.13	.16
Difference (percent)	36	23	30

[1] Values for ponded rates are extrapolated down to the average level at which the seepage meter rates were measured.

Table 1 shows a comparison of seepage rates obtained from ponding tests and those estimated by seepage meter tests. Rates measured with the seepage meter are for an

[5] Bouwer, Herman, and Rice, R. C. Seepage meters in seepage and recharge studies. Jour. Irrig. and Drain. Div., Amer. Soc. Civ. Engin. Proc. 89 (IR 1): 17-43. 1963; and U.S. Department of Agriculture. Basic instructions for falling-head seepage meter technique. Agr. Res. Serv., Water Conserv. Lab. Rpt. 1, 11 pp. 1964.

[6] Brockway, C. E., and Worstell, R. V. Groundwater investigation and canal seepage studies. Idaho Engin. Exp. Sta. Prog. Rpt. 2. 1967.

average centerline water depth of 21 inches, while the canal operating depth was 5 to 5½ feet. The ability of the meter to accurately reflect actual seepage rates under similar conditions is evident. The meter rates in both instances are about 30 percent higher than the corresponding ponded rates. The ponded seepage rate could possibly be lower than that of an operating canal if suspended sediments and algae tend to settle to the bottom and partially seal it under conditions of zero velocity. A 30-percent error in estimating the seepage rate in a canal with low losses may not be economically important. However, a 30-percent error in the estimate for a canal with a higher seepage loss could result in an erroneous justification of a lining program.

Another reason for the 30-percent difference between the ponded rate and the seepage meter rate may be the difference in location of the water surfaces during the tests. The water-surface slope during the seepage meter tests was essentially equal to the friction gradient, or about 0.9 foot per half-mile. The ponded rate used for this comparison is computed at a level water surface elevation corresponding to the average elevation of the sloping water surface during seepage-meter tests. The actual seepage area for the ponded condition is not identical to the area sampled by the seepage meter tests. An estimate of the magnitude of the difference attributable to this effect is difficult. The meter itself may not measure the true seepage rate of the soil into which it is inserted.

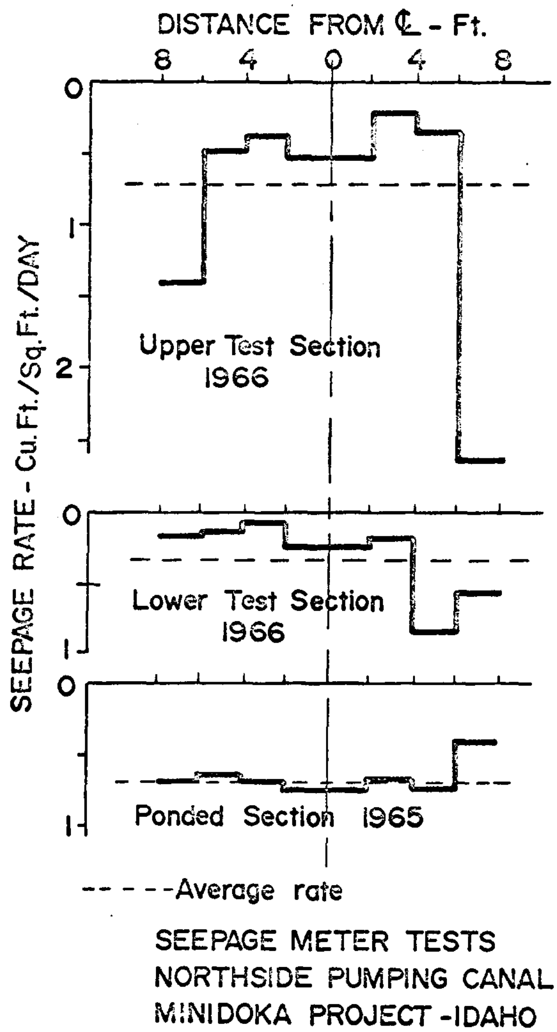

Figure 1.—Variation of seepage rate in cross section.

Disturbance of the soil during insertion of the meter bell can cause indicated seepage rates to be higher than actual. Inserting the bell may cause a "crack" through the restricting layer. An insufficient seal between the bell and the soil can also cause errors in measurement. However, with the ARS meter, the seal is always checked before each measurement (see ARS Water Conserv. Lab. Rpt. 1 listed in footnote 5). Warnick showed that with a constant-head-type meter, stepping on or pushing the meter bell in by hand caused measured seepage rates to be as much as 23 percent greater than the ponded rate.[7]

Differences in seepage rates across the channel were detected with this meter. In the 1966 tests, employees of the irrigation district shaped both sides of the upper pond before the seepage meter tests. This process removed the berm and disturbed the impeding layer on the side slopes, but did not disturb the canal bottom. In the lower pond, only one side of the cross section was shaped. Figure 1 shows the variation of seepage rate in the cross section for the three test reaches. The measured seepage rate should be lower near the outer edges of the wetted area where the effective water depth is less. The 1966 tests indicated higher seepage rates in areas where the impeding layer was disturbed. The comparison was tested statistically to assure that it existed.[8] This difference in rate within the cross section was not apparent for the 1965 tests which were made before shaping operations. Small differences in rates occurred throughout the length of each test reach, but no apparent physical reason could be found for this variation. Attempts to extrapolate 1966 measured seepage meter rates to operating depths were unsuccessful. Estimates using the measured hydraulic impedance of the restricting layer were not possible because the layer had been disturbed on the side slopes.

The seepage rate measured by the meter in the 1965 reach and extrapolated to operating depth was 1.42 c.f.d. This was compared to a seepage rate ponded at operating

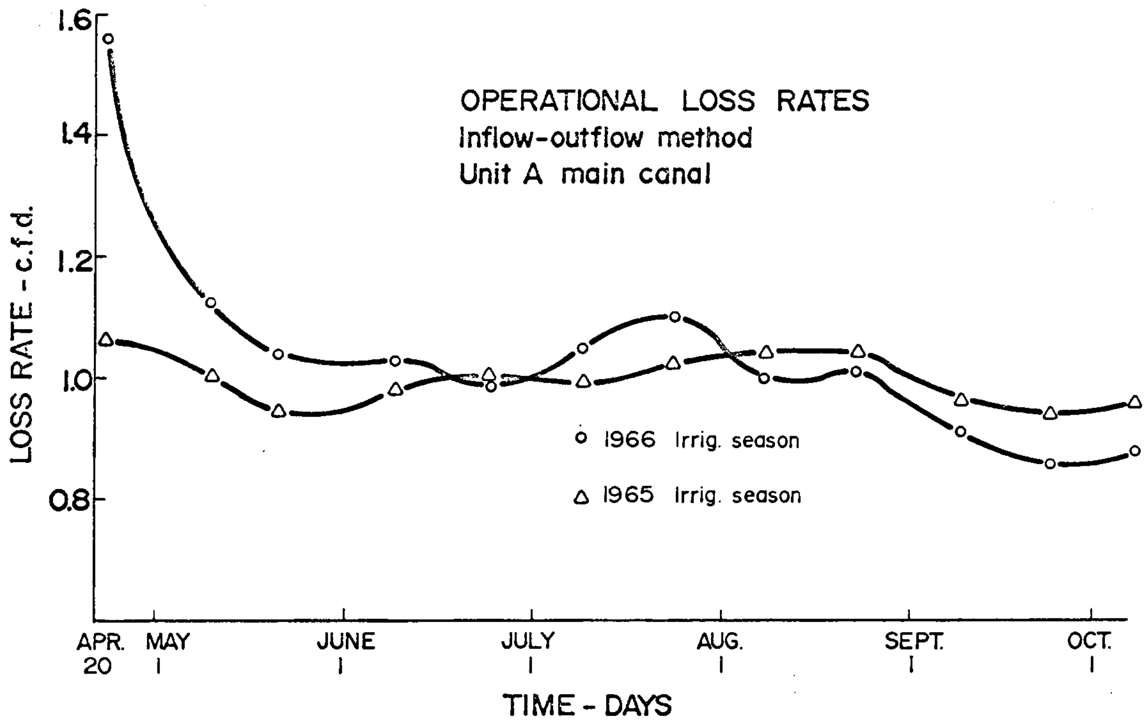

Figure 2.—Operational loss rates inflow-outflow method Unit A Main Canal.

[7] Warnick, C. C. Problems in seepage evaluation and control. U.S. Dept. Agr., ARS 41-90, Seepage Symposium Proc. 1963: 132-137. 1965.

[8] Ostle, Bernard. Statistics in Research. Ed. 2, Iowa State Univ. Press, Ames, Iowa. 1963.

depth of 0.67 c.f.d. The difference could be caused by the consolidated silt layer in the canal cross section, or, because of insertion of the seepage meter, the sealing layer could have been disturbed, particularly along the wall of the seepage meter. The measured hydraulic impedance in that case would be less than the actual value.

The inability to estimate operating level seepage loss rates by extrapolating measurements made with the ARS meter tends to counteract the advantages of its ease of operation and apparent accuracy. Further studies are underway to develop a meter using the variable head principle which can be used efficiently in an operating canal.

INFLOW-OUTFLOW MEASUREMENTS

The Bureau of Reclamation, as part of a study of water use on federally irrigated projects, instrumented the 4.5-mile reach of the Main Canal to determine operational losses. This system is one of the best installations of this type which has been made. Losses in the total reach length were computed for 2-week periods during the irrigation season and expressed as cubic feet per square foot per day (c.f.d.) over the entire wetted area. This loss rate is not a seepage rate per se, but includes other operational losses. A comparison of loss rates over the 1965 and 1966 seasons is shown in figure 2. Definite seasonal fluctuations are evident and are reasonably repeatable for the 2 years. The loss rates were considerably higher than the ponding seepage rates of 0.60 to 0.70 c.f.d.

Determining loss rates by inflow-outflow methods is usually very costly and probably should not be used solely to estimate seepage losses. The installation on the Unit A Canal involves over 20 recording flow-measuring devices, which are costly installations. With a large number of flow-measuring devices, the probable error in the estimate of loss rates can be quite large. Any error would be more significant in reaches with low loss rates.

ESTIMATING REQUIRED NUMBERS OF SEEPAGE METER TESTS

The following procedure can be used to estimate the number of seepage meter tests required to obtain a reasonable average value of the seepage rate from a reach of a canal.

A number of assumptions are required in the analysis: (1) The locations of measurements in the canal cross section were randomly selected, (2) the individual measurements were performed by competent personnel using the proper technique, (3) variability of the soils in which the known data sites were obtained approximated the variability of all other soils encountered, and (4) the distribution of seepage rates is normal. A level of confidence to be used in seepage meter tests can be defined as that which is based only on the variability of individual measurements as affected by random variation of soils and human techniques.

Using a Student's t distribution, the confidence interval for the mean is defined by

$$\overline{X} - \mu = \frac{ts}{\sqrt{N}} \tag{1}$$

where

$\overline{X}$ = observed sample mean, or the mean of a number of seepage meter tests,

μ = population mean, or the mean of all possible tests,

s = sample standard deviation,

t = probability function which is dependent on the desired confidence level and the number of tests,

N = the number of tests.

Expressing the confidence interval as a percentage of the computed mean $\overline{X}$:

$$\frac{D\overline{X}}{100} = \frac{ts}{\sqrt{N}} \tag{2}$$

where

D = maximum percent by which the computed mean might vary from the true mean at a given probability level.

For a selected value of D and estimated values of s and $\overline{X}$, the required number of tests, N_c, can be estimated by

$$N_c = \left(\frac{100\ ts}{D\overline{X}} \right)^2$$

or

$$N_c = \left(\frac{CVt}{D} \right)^2 \qquad (3)$$

where $CV = \dfrac{100s}{\overline{X}}$ of the percent coefficient of variation.

Equation 3 must be solved by trial and error since t is a function of N_c.

With a selected 90-percent confidence level, a D of 20 percent, and estimated CV, equation 3 will give the number of tests required so that 9 times out of 10 the average of the group of seepage meter measurements will be within 20 percent of the true mean.

If individual seepage meter measurements are biased and do not accurately represent the seepage rate at a point, the sample mean and the true mean will be biased in the direction of error. The true mean is then not necessarily equal to the true seepage rate. Determining the accuracy of the seepage meter tests is possible only by comparing the computed mean with actual seepage rates determined by ponding.

Equation 3 can be solved graphically using figure 3, which was computed for a confidence level of 90 percent. Initial estimates of N_c can be made based on estimated values

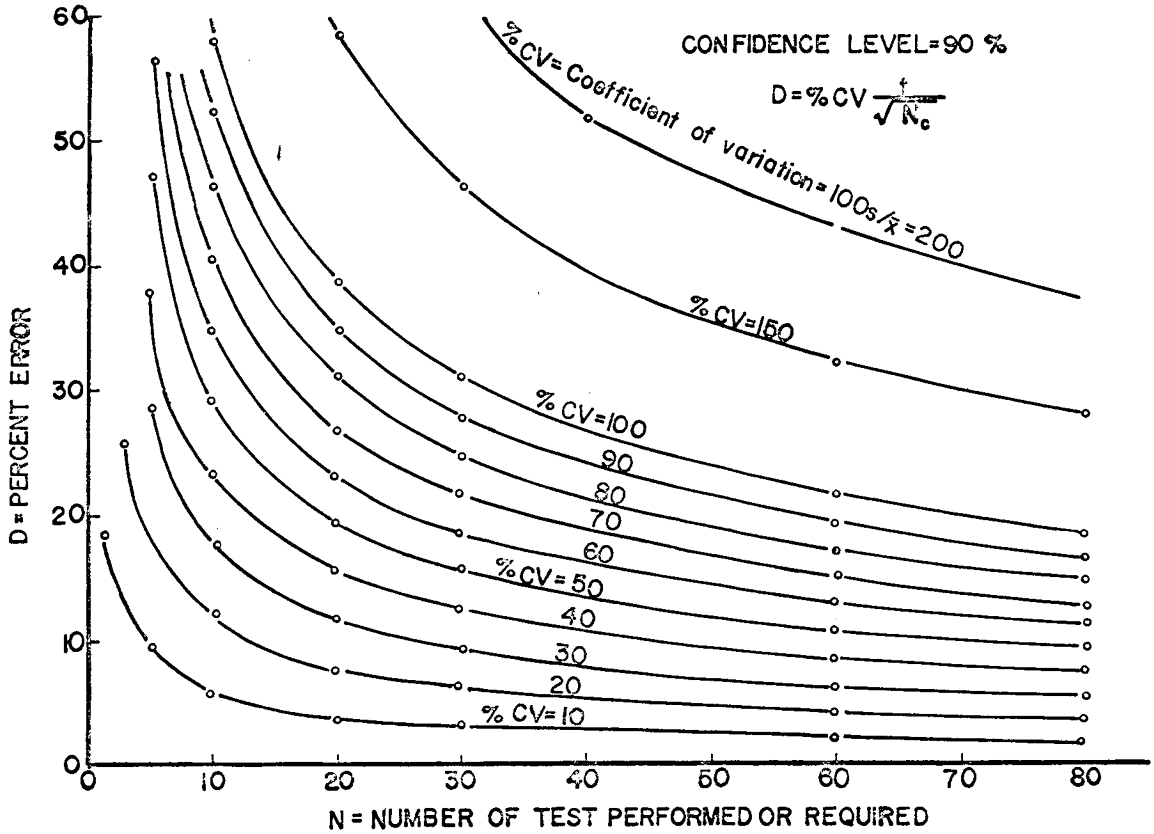

Figure 3.—Seepage meter study — determination of required number of tests.

of s and $\overline{X}$ and the computed value of CV. After a number of tests are run, figure 3 can be used to obtain a new estimate of N_c based on computed values of CV.

An average seepage rate can usually be estimated by examining the soil type and canal geometry. Past results of seepage meter studies can be used to obtain estimates of s. In the seepage meter tests with the ARS meter in 1965 and 1966, the average standard deviation of 17 groups of tests for a total of 156 tests was 0.538 c.f.d. A similar analysis of 54 sample groups for a total of 762 tests run with the U. S. Bureau of Reclamation meter on various types of soils showed an average standard deviation of 0.508 c.f.d.[9] A reasonable initial estimate of the standard deviation is probably about 0.5 c.f.d.

TABLE 2.— Statistical analysis of seepage meter tests, Northside Pumping Canal Test Section, 1965

Item	Initial estimate	Number of tests completed 10	20	30	40	51	61	71
Mean seepage $\overline{X}$ (c.f.d.)	0.75	0.727	0.658	0.614	0.661	0.643	0.693	0.673
Standard deviation s (c.f.d.)	.5	.481	.410	.357	.364	.387	.448	.432
Coefficient of variation (%)	66.7	66.2	62.4	58.2	55.1	60.1	64.6	64.2
Tests required N (No.)	32	31	28	25	22	26	30	29
Actual D (%)	—	39	24	18	15	14	14	13

Table 2 is an example of the use of this procedure for obtaining an initial estimate of N_c and then revising the estimate after a number of tests have been obtained. Estimates of the seepage rate for the Portneuf silt loam soil in the 0.5-mile reach of the canal varied from 0.5 to 1.0 c.f.d., so an initial value of 0.75 was chosen for $\overline{X}$. The initial values in table 2 are based on a confidence level of 90 percent and a D value of 20 percent. For this series of tests, the required D was obtained after about 30 tests and the testing could have been terminated. Similar analysis for confidence limits other than 90 percent could be made using equation 3, or curves similar to figure 3.

DISCUSSION AND CONCLUSIONS

Of the available methods for evaluating seepage losses, the ponding test is the most accurate but the most expensive. The use of seepage meters for obtaining estimates is fast and economical. However, new types of meters capable of functioning in canals at operating depth should be studied. Almost all the available meters are capable of measuring seepage with reasonable accuracy at a point, but discretion must be used in the amount of confidence placed in average values determined from meter tests. The procedure outlined for estimating the number of meter tests required can be used to judge the confidence to be placed in any group of tests.

Inflow-outflow methods are usually too expensive to be used for short-duration seepage measurements. However, a good installation does indicate seasonal changes in loss rates. Accuracy of inflow-outflow determinations is limited by the flow-measuring devices, but for canals with large seepage losses, inflow-outflow methods may be the most expedient and sufficiently accurate.

[9]Engr, P. 'F.' January 1965. Memorandum to E. J. Carlson, Special Investigations Section, Hydraulic Laboratory, U.S. Bureau of Reclamation, Denver, Colo.