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In This Issue:

Measuring Seepage in Irrigation Canals by the Ponding Method

The Irrigation Operation and Maintenance Bulletin is published quarterly, for the benefit of irrigation project people. Its principal purpose is to serve as a medium of exchanging operation and maintenance information. It is hoped that the material in this issue, which summarizes procedures for performing ponding tests to measure seepage losses from canals, will result in improved system efficiency and reduced maintenance costs.

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Division of Irrigation Operations
Office of Chief Engineer
Denver, Colorado

COVER PHOTOGRAPH:
This is a view of Recorder Station upstream from Station 581+40, on the Eden Project, Upper Colorado Basin, Wyoming.
Photo P153-D-27834

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
DIVISION OF IRRIGATION OPERATIONS
Denver, Colorado 80225

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MEASURING SEEPAGE IN IRRIGATION CANALS BY THE PONDING METHOD

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INTRODUCTION

Seepage losses from canals have been a problem to irrigation districts and irrigation engineers for a long time. As the need for conservation of land and water resources grows, the importance of accurate knowledge concerning this type of water loss is increasing. The technique which offers the most accurate method now known for determining rates of loss is the ponding method, the use and importance of which is growing rapidly.

Studies using the ponding method can answer such questions as:

(a) How much does a given canal leak? (b) Where are the major leakage areas? (c) Should a canal be lined? (d) Is an existing canal lining effective?

Many factors affect the rate of seepage loss from a canal. Some of the more obvious are listed here:

1. Permeability of soil traversed by canal
2. Depth of water
3. Wetted area
4. Location of water table relative to canal invert
5. Slope of subgrade soil structure
6. Flow velocity
7. Soil and water temperatures
8. Entrained air in soil
9. Ground-water inflow
10. Atmospheric pressure
11. Soil and water chemistry
12. Capillary attraction
13. Surface seal in canal by silt, etc.

The relative importance of each of the above factors has not been definitely determined, though it is known that one may offset another, and some may even alternately increase and decrease seepage rate. Moreover, with so many potential factors affecting seepage, it is impossible to write simple equations expressing their relationships. However, it is the purpose of this bulletin to outline as briefly as possible the procedures that should be followed and equipment needed to provide satisfactory results in making a ponding test.

A more detailed treatment of this subject and the source of material for this article is "Hydraulic Laboratory Report, HYD-459." It can be obtained on loan from the Bureau of Reclamation Library, Denver Federal Center, Denver, Colorado 80225.

MEASURING SEEPAGE IN IRRIGATION CANALS BY THE PONDING METHOD

Selecting the Pond Site

Several factors may enter into the selection of a pond site. The purpose for the seepage measurement may automatically dictate the site. For example, if the water table under croplands adjacent to a certain length of canal has risen to a level which is causing crop damage, then the test reach should probably parallel affected properties. If the purpose is to learn the effectiveness of a lining method or material, or to determine a loss rate for a particular soil type, more latitude may be allowed in placement of a pond.

As a general rule, it is desirable to avoid selecting a reach in a canal where it is difficult to determine the wetted cross section, and where turnout leakage cannot be stopped. If possible, the pond should be free from reaches in which the subgrade materials vary considerably in composition. This is particularly true if the measured seepage rates are to be considered as representative of a certain soil type or condition.

Determining the Length of Pond

The length of the pond is an important consideration. In general, the length should be great enough to make the sum of the pond end areas a very small percentage (not more than 3 percent) of the total wetted area. Since the seepage per unit area through or under temporary dikes can be greater than through a unit area of the bottom or sides of the canal, the effect of the end areas on rates of loss can be minimized by observing this precaution.

As a guide to setting the length, in one canal with a bottom width of 16 feet a test was made in a pond 1,400 feet long and in another with a bottom width of 26 feet, the test pond was 800 feet long. The pond end areas in the first canal were about 0.4 percent of the wetted area, and the corresponding value in the second canal was about 1.5 percent. To keep the percentage of end area low the pond should have a minimum length of about 60 times the depth of water.

Constructing the Ponded Section

Many methods or combinations thereof can be used to create the ponded section. How the dikes are made will depend primarily on the size of the canal and materials at hand.

Dams may be built of canvas or plastic held in place by a timber at the top and dirt thrown along the edge on the cross section. Such dams are usually restricted to small channels in which the water depth is less than 2 or 3 feet. A heavy-weight canvas treated with water-proofing will usually function with a minimum of leakage. Heavy plastic material may also be used.

Another method very often used for constructing the ponded section, is to build earth dikes at each end of the pond. For an average size canal, the material is usually pushed into place with a dozer. If the canal is dry during dike construction, the dozer can compact the soil by repeated trips back and forth across shallow lifts. Restricting each lift to 6 or 8 inches will make it possible to secure adequate compaction in this manner. The base of the dike is usually about as wide as the total width of the canal. Construction of dikes while there is water in the canal is not recommended.

As the size of the dikes required becomes larger, greater care in construction is necessary. In an unlined or earth-lined canal, a cutoff trench at least a foot deep should be excavated along the cross section through sand and silt deposits and into solid material. This allows placement and compaction of selected soil and destroys any thin layer of materials which because of gradation, organic content, and moisture condition, may provide relatively low resistance to horizontal shear forces between the dike and subgrade. It also acts to key the compacted soil above into the subgrade, and lengthens the percolation path under the dike. Care should be taken to give sufficient base width to the dike, and the slopes of the fill should not be steeper than 1-1/2:1, to prevent slippage of soil into the pond when it becomes saturated. The space required for pumping equipment in tests in which the pond is filled from a reserve water supply in the canal may dictate the top as well as bottom width of a dike.

Leakage from the ponds in even large canals can be eliminated by covering the pond side of the dikes with sheet plastic from 4 to 8 mils thick. The plastic must be placed before filling the pond. The edges can be held in place in shallow trenches about 12 inches deep, with soil shoveled carefully over the plastic in order not to puncture the plastic sheet. This treatment is of particular value where the only readily available fill soil is sandy. A dike so constructed may require less yardage for stability than one without a plastic cover. It is always good practice to use plastic on all dikes to insure water tightness and stability, where this is possible.

In small or medium size canals, where water depth is less than 5 or 6 feet, it is possible to pass water over an earth dike protected with sheet plastic. Thickness of 4 mils or greater will be satisfactory. The entire dike must be covered from upstream to downstream inverts, and the plastic should extend along the canal sides far enough to allow it to be held firmly in place with fill dirt. The joints should be at right angles to the direction of flow, and a lap of not less than 1 foot is necessary. If plastic cement is available, overlapping sheets may be joined. Flow over the dike should be limited to prevent excessive erosion by the velocity on the downstream side of the dike.

When earth dikes are to be installed in a concrete-lined canal, it is impracticable to excavate a cutoff trench. The base width of the dike must then be great enough to withstand the hydrostatic pressure in the pond, and percolation paths made sufficiently long so that leakage is reduced to a negligible amount. Piping along the line of contact must not occur. Generally speaking the base width of the dike should be greater than that used in an earth canal, and plastic covering of dikes is almost always advisable.

When water must be passed through a dike to fill a pond or passed to another pond downstream, it will be necessary to install gated culvert pipe. The culvert should be provided with one or more cutoff collars, and the surrounding materials must be carefully compacted to prevent piping along the corrugations.

In some instances it will be convenient to store water in a pond above the upstream dike for use in refilling the test section. When this is done it may be desirable to build a second dike to isolate the test reach, placing this dike so that the toes of facing slopes are separated a few feet as illustrated in Figure 8, on page 12. Thus it will be possible to observe the watertightness of the pond dikes. If only one dike is built it is recommended that it be covered on both sides with plastic.

It is excellent practice to use existing check structures or check drops to pond water. Canvas or plastic is usually placed over the upstream side to cover open joints and to prevent leakage around the ends of the planks. Canvas can be held in place along the edges and bottom by packing soil against it. Where a pond is formed above a check, unless another structure is available upstream, a dike should be used at the upstream end. This will avoid excessive length and near zero depth at the upstream end with design depth at the downstream end. If the check is gated, it will probably be necessary to seal each gate against leakage, either by using canvas as above stated, or by packing the gate with a watertight material such as oakum.

<u>Test Equipment Required</u>

The equipment needed to conduct ponding tests is simple to operate, but precautions should be observed when installing it. The equipment which may be used includes one or two hook gages; one or two staff gages; a water stage recorder; stilling wells for the hook gages and recorder; and, in some cases, an evaporation pan. Figure 1, on the following page, shows a recorder equipped with an 8-day clock, a spined float pulley, graduated float tape and index bracket to provide direct indication of gage heights. Figure 2, page 5, shows both a Hook Gage and a Staff Gage.

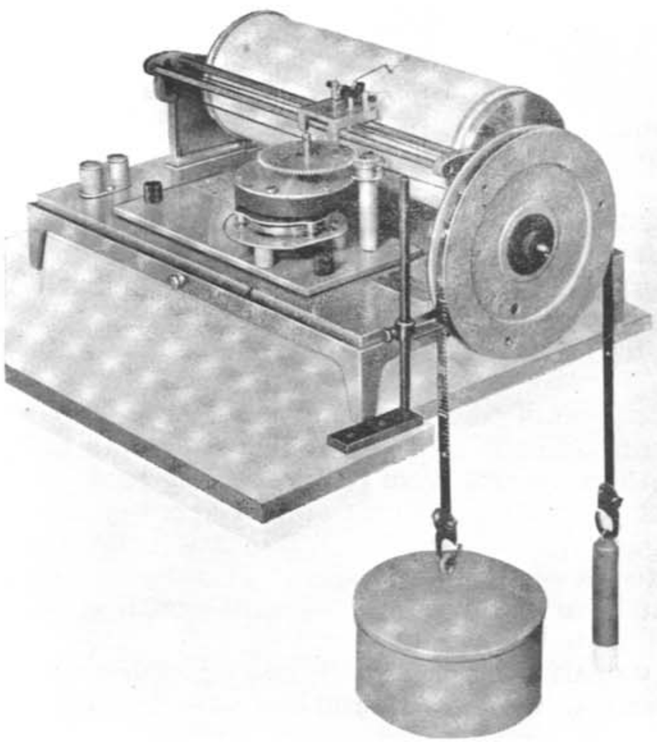


Figure 1, Photo PX-D-53977

If the pond is long or subject to unusual wind conditions, hook and staff gages are paired for use at upstream and downstream ends of the pond. The recorder is usually installed at the lower or midpoint of the pond. During windstorms, the water surface or the pond may not be horizontal throughout the length of the pond; but, by having gages at each end, average water surface elevations can be determined. If the pond is reasonably short (less than a quarter of a mile), one staff gage, a hook gage and a recorder is all that will be required.

It is possible to run a ponding test with less equipment (such as a staff gage and a recorder) to determine the water surface elevation; however, the precision used to obtain field data determines, to considerable extent, the accuracy of the results obtained in the tests. In all cases, a staff gage is essential.

The staff gage is usually a standard enameled gage frequently used in irrigation projects to indicate water depths and is scaled to 0.01 feet.

The water stage recorder usually has 1:1 staff gage versus chart reading ratio and a time scale of about 9.6 inches per day.

The hook gage used is usually a laboratory type which can be read to 0.001 foot with the aid of a vernier.

It is advisable to use hook gages when seepage rates are low and the time interval is short between readings; however, the decision whether or not to use hook gages rests with the test observer.

Figure 2, Photo PX-D-25228

Evaporation pans and rain gages are not usually necessary; however, if evaporation is significant, an evaporation pan should be installed. Figure 3, below, shows an Evaporation Pan set on the dike of a seepage pond.

Installing Test Equipment

Each staff or hook gage should be referenced to canal elevations so that depths of water in the pond can be compared with design or operating depth. An assumed elevation can be used for setting the equipment provided it is referenced to the canal survey. Zero elevation for staff gage, hook gage and recorder should be the same.

Figure 3, Photo PX-D-25230

The gages can be installed on vertical uprights (2 by 4 or 4 by 4 timbers) that have been firmly positioned near the edge of the pond. If the canal is small, the upright can be placed so that an access platform is not needed to read the gages.

In larger canals, a walkway will probably be needed to reach the gages. Under no circumstances should the timber for gages be an integral part of the walkway framing, since repeated trips over the walkway to read the gages would force the upright into the subgrade and change the gage setting. Figure 4 shows how the Hook and Staff Gages can be mounted separate from access platform.

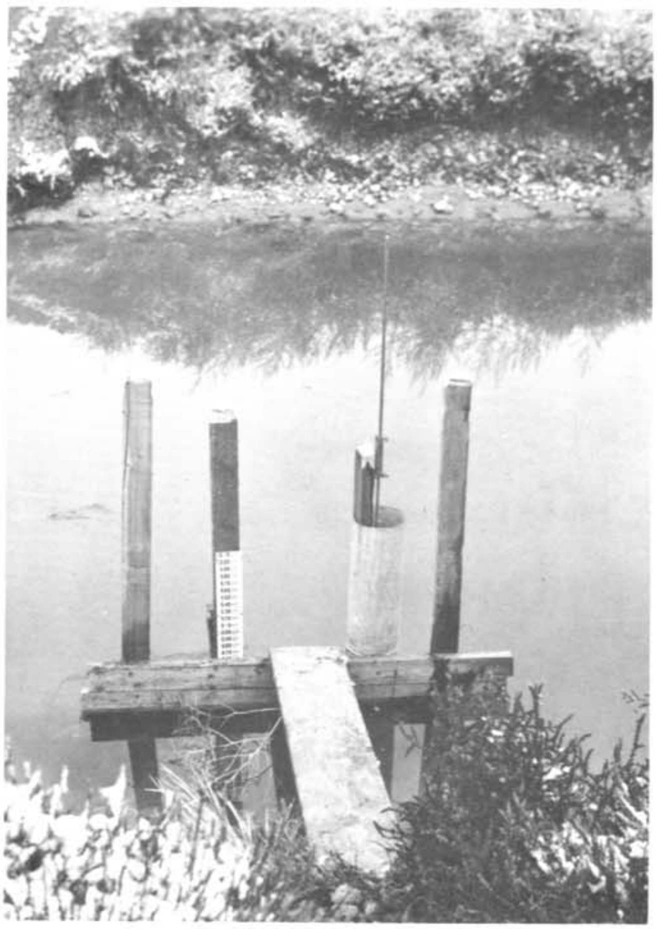


Figure 4, Photo P596-D-18417

The staff gage reading can serve as a check of the hook gage and recorder readings; and, should the hook gage be accidentally disturbed, the staff gage can be read until a resurvey establishes a new elevation on the hook. A check on the hook and staff gage elevations may be made when the pond water surface is absolutely still on a calm day.

Motion of the water surface makes accurate vertical positioning of the hook difficult. A stilling well around the hook should be provided to minimize the movement. While elaborate shop-made stilling wells have been used, one or more lengths of 6-inch-diameter stovepipe will serve the purpose quite well, as shown in Figure 4. The stovepipe is usually nailed to the gage timber at top and bottom. To restrict flow of water into and out of the pipe, the lower end should be crimped nearly shut. A damping effect is thus achieved which greatly reduces the rise and fall of the water in the pipe compared to the fluctuations in the pond.

A convenient method of installing the water stage recorder is to use a 50-gallon oil drum for a stilling well with appropriate cutouts in the top for the recorder cables, etc. Other temporary setups can be made as illustrated in Figure 5, it shows a barrel used as recorder stilling well and staff gage, and Figure 6 shows turnout gate structure used for installation of water stage recorder.

Figure 5, Photo P153-D-27829

Relating Effects of Evaporation and Rain

Under ordinary circumstances, as explained previously, evaporation pans and rain gages are not usually necessary. However, there will be evaporation from the pond surface; also, of course rain can occur.

Figure 6, Photo P448-D-39233

Accordingly, good judgment must be exercised by the observer in deciding on the necessity for rain or evaporation measurements. Prior to starting tests, the expected evaporation rate should be related to a rough estimate of the seepage rate.

For example, if the drop in water surface on a pond is 1.5 feet per day, 0.04 foot of evaporation would not be important. On the other hand, in a canal with a low loss rate, the evaporation correction may be significant even during periods of cool weather. For instance, if the drop in a pond from seepage is 0.10 foot per day and evaporation is 0.02 foot per day, then the evaporation should be measured.

If evaporation and precipitation are to be considered, evaporation rates may be obtained from a nearby weather station, and can be used if they are representative of those of the test site, or a temporary installation can be made utilizing an evaporation pan adjacent to the pond, as previously shown in Figure 3. The one advantage of the latter is that the effect of precipitation at the site can also be determined.

Observation Wells

The use of observation wells to supplement ponding studies is occasionally worth the added expense. They may be used to log the subsurface soils, to locate the water table, to observe the slope in hydraulic gradient from uphill to downhill sides of the pond and to indicate the effectiveness of linings in place. However, under ordinary circumstances observation wells are not needed and so will not be discussed here.

Surveying the Pond

A survey to establish the shape of the pond is usually required. It will be an advantage to survey before filling the pond to enable simultaneous testing and computing of necessary data from the survey notes, so that, at the conclusion of the ponding tests, computation of seepage rates may proceed without delay.

A comprehensive survey is not necessary for all tests. For instance, in the case of concrete-lined canals, very few cross sections will probably be required to establish the as-built shape. If a recently built canal is earth or earth lined with little erosion or deposition of materials, the cross section may be quite uniform. In this case, the cross section need be checked only at a few stations.

Where detailed survey is required in older earth canals, cross sections should be taken about every 50 feet and elevations measured to within 0.1 foot. The survey should establish the shape of the canal to an elevation about 1 foot above the anticipated water test level.

The condition of the canal may be used as a criterion in deciding at what intervals to cross section. In a canal that is irregular in cross section, the intervals required to obtain a satisfactory record of shape may be short. Test personnel must use their best judgment to secure measurements of appropriate accuracy.

If the pond is short, 1,000 feet or less, consideration should be given to taking cross sections about every 50 feet to increase accuracy. When the pond is very long, such as one which has been created upstream of a check structure in a canal with a very gradual slope, cross sections every 100 feet may be reasonable.

As mentioned previously in connection with the installing of test equipment, exact elevation is not necessary to establish temporary bench mark elevations on nearby structures. These benches can be used to survey the pond, set the hook gage point and the staff gages, and determine operating water surface elevation.

Calculations Using Survey Notes

From the survey of the pond, the following are calculated:

a. Water surface width according to elevation. - This is the water surface distance across the canal.

b. Wetted perimeter according to elevation. - This is the distance along the ground surface under water, or that part of a cross section of the canal wet by the water.

Note: It will not be necessary to make a separate measurement of the length of the pond, since length enters into calculations for seepage loss through the cross-section stationing, as discussed on page 14, and shown in the basic equation at the bottom of Table IV, on page 21.

The first step toward calculation of the seepage loss is the compiling of Tables I and II, as shown on pages 18 and 19. This includes plotting the canal cross sections to a scale that will make possible the measuring of water surface widths and wetted perimeters to within 0.1 foot as shown in Figure 7, on the opposite page. Noting the range of water elevations to be covered in the tests, water surface widths and wetted perimeters are scaled on each cross section from an elevation just below the lowest test elevation to an elevation slightly above the highest test elevation. The increments of elevations used will depend on the size of the canal, depth in the pond, and range of test depths. For shallow canals of short bottom width, it is advisable to compile tables of water surface widths and wetted perimeters for each 0.1 or 0.2 foot of depth. In deeper and wider canals, the increment may be changed to 0.3 foot or more without seriously affecting the accuracy of computations.

Table I and II also show each column under a particular elevation averaged for all stations to obtain the representative characteristics for the entire pond. Since elevations measured in the course of the tests will rarely correspond exactly to those in the table, it will be necessary to interpolate between average values for correct water surface widths and perimeters.

Filling the Pond

Gravity flow or pumping may be used to fill the test pond. The method will depend on the conditions that prevail at the site and the size of the canal. The following possible courses of action are suggested:

a. Release water to form a supply reservoir at the upstream dike, and pump the water over the dike into the pond as shown in Figure 8 on page 12.

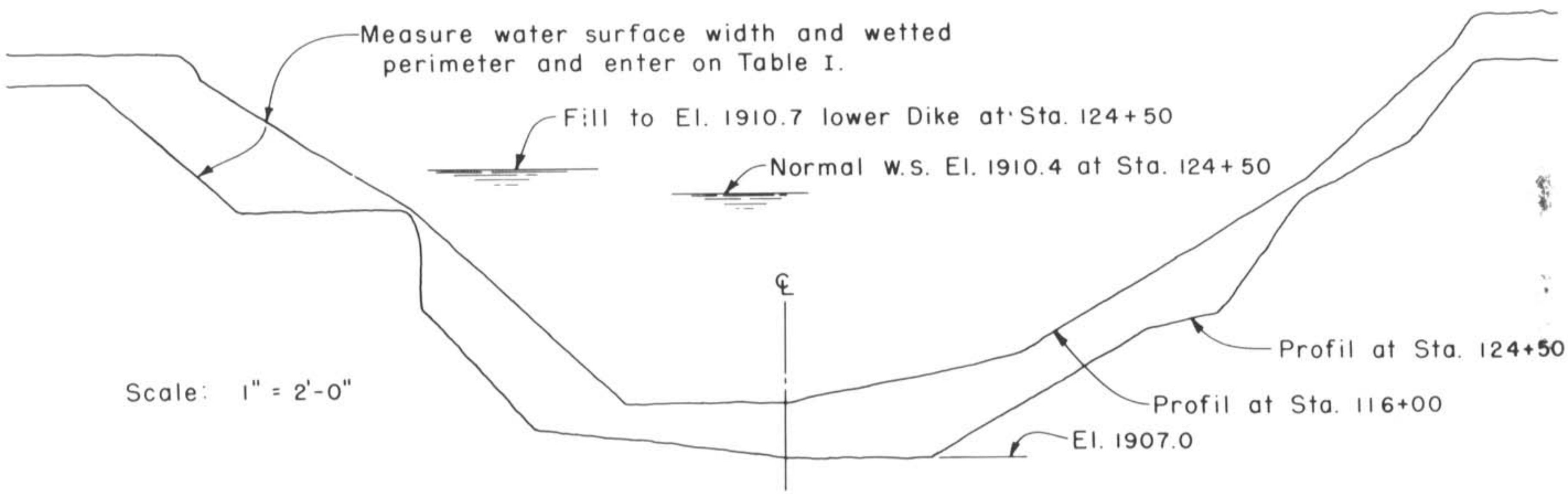
b. Allow water to flow into the pond by gravity (over a dike covered with plastic).

ORIGINAL DESIGN

Q = 49 r = 1.72
U = 1.91 h = .025
S = .0005 A = 25.5
Normal water depth 3.0'
Bottom width = 4'
Side slopes $1\frac{1}{2}:1$

NOTE

Pond extends from Sta. 116+00 to Sta. 124 + 50



TYPICAL CROSS SECTION OF TWO CROSS SECTIONS OF A POND

FIGURE 7

Double Dike Installation Showing
Four Pumps For Filling Pond

Figure 8, Photo PX-D-25225

c. When using check structures, release water until it flows over the stoplogs at the checks, then stop the inflow.

d. In a series of ponds, fill the reach of canal by gravity to the upstream dike of the upstream pond, and allow water to flow through gated culverts in the dikes to downstream sites.

In the ponding test, it is wise to plan on filling the pond at least twice; and if the test reach is known to leak appreciably provision should be made for a third filling. Only by repeatedly filling the pond can one be reasonably sure that bank storage has been satisfied and that paths of percolation are as active as in an operating canal.

The starting depth in the pond should be slightly higher than the design or operating depth to secure data above and below that level. This procedure should be followed even though the operating level is below design depth on a project not yet fully developed.

When more than a single filling is required, the refilling may be more difficult than the initial one. Except when gated pipes through the dikes have been provided, water must frequently be pumped into ponds utilizing upstream and downstream dikes. Deciding when to refill a pond will depend on the rate of water surface drop, the depth of the pond, the length of the pond, and the availability of water to accomplish refilling. When the water surface drops rapidly, several tenths of a foot per day, refilling may be necessary by the third day, particularly if the pond depth is 5 feet or less. However, when the rate of drop is less than 0.1 foot per day, a pond of 4-foot depth or more can be allowed to seep up to 2 weeks and may not require refilling.

Taking Readings

Measurement of the rate of drop in the water surface begins after the pond is filled, all gages are set, and the recorder is operating. A suggested form for recording staff and hook gage data during the test is shown in Table III, page 20. Notations to indicate upstream and downstream gages should be used. The reading of each hook gage is recorded to the nearest 0.001 foot and the staff gage to 0.01 foot. The extra colmns may be used to record the wind and wave conditions prevailing at the time of reading and other information worth noting. The time of each reading should be recorded to the nearest 5 minutes. This practice will usually enable the observer to read the gages at both ends of a pond within a single 5-minute interval. In small ponds where the seepage rate is high, it may be advisable to record the reading to the nearest 1 minute.

Within a few hours after the initial readings of the gages and recorder, test personnel will have reasonable indication of the rate of fall of the water surface. From this knowledge, the required frequency of succeeding readings can be determined. If the pond seems to have a high loss rate, readings every 1 to 4 hours may be required; on the other hand, for a pond showing a very slow rate of drop, less frequent readings will be satisfactory. Staff gage readings and the time of day should be written on the recorder chart each time the gages are read.

In one canal test with a seepage loss of approximately 1.3 cfd,[1] gage readings were made about every 4 hours, day and night. On another canal test where the loss rate was less than 0.05 cfd, readings were taken in early morning, midafternoon, and late evening, with no readings between 10 p.m. and 8 a.m. Thus personnel must decide from test circumstances the schedule for taking of data.

A graph of water surface elevation versus elapsed time can be made to show a changing or steady rate of loss. The graph can be used to decide whether additional fillings of the pond will be needed or if an error in water surface level has been made. If a water stage recorder is used, a plotting of the elevation-time curves is not necessary, because the chart will automatically make the graph.

Computing Loss Rates

Although seepage loss data can be set up for computation by computers, the manual method using tables is presented here and is dependent upon knowing the water surface width and the wetted perimeter of canal ponds for elevations of water surface during the test. These figures can be obtained from Tables I and II previously discussed.

Table III also previously discussed is used to record information obtained during the ponding test.

The information contained in Tables I, II, and III, is sufficient for computation of loss rates. To facilitate these computations, the use of Table IV on page 21, is also suggested. In using Table IV: -

a. Data from Table II are entered in Columns 1 (date), 2 (time), and 4 (water surface elevation). Values in Columns 3 (elapsed time) and 5 (drop in water surface) are computed from Columns 2 and 4.

b. From Table I, an interpolated value for water surface width, Column 6 can be found.

c. Column 7 is calculated from Column 6.

1/Seepage losses from canals are generally expressed in Bureau of Reclamation Studies in cubic feet per square foot of wetted area per day and abbreviated to "cfd."

d. The value in Column 8 is the product of Columns 5 and 7.

e. The wetted perimeter in Column 9 is computed from the data in Table II. Since the wetted perimeter decreases as the water surface drops, it is necessary to use a value that is the average of wetter perimeters for beginning and end of the test time interval.

f. Column 10 is the average wetted perimeter, calculated from Column 9.

g. Column 11 is calculated from Columns 3 and 10.

h. The desired seepage rate in Column 12 is obtained by dividing Column 8 x 24 by Column 11.

To facilitate computations, data in Columns 1, 2, 4, 6, and 9 should be entered on odd-numbered lines; and data in Columns 3, 5, 7, 8, 10, 11, and 12 should be written on even-numbered lines.

Approximate Method of Estimating Seepage

On ordinary earth canals, an approximation of the seepage rate can quickly be made by using the following equation:

$$(\text{cfd}) = \frac{\text{Drop in w.s. x } 0.85 \text{ x } 24}{\text{Hours of run}}$$

Note: The factor 0.85 used above is approximately equal to the water surface width divided by the wetted perimeter, and should be verified by a sample measurement or calculation.

Interpreting Test Data

The purpose of the ponding test is to measure the seepage rate accurately. In a general way, a reach of canal might be said to be "tight," "borderline," or "leaks like a sieve." A tight canal might have a seepage rate of 0.03 to 0.10 cfd. A poorly lined canal or seriously leaking unlined canal might have a seepage rate of 0.50 cfd or higher. Leakage as high as 3.0 cfd has been recorded on some unlined canals. Such losses, of course, cannot be tolerated for long periods - on most canals.

It is possible for a ponding test to indicate a loss rate which alone does not always provide the information needed for deciding whether to line a canal reach. For example, land with insufficient natural drainage adjacent to a canal may have a high-water table during the irrigation season or water may be standing in shallow depressions. The loss rate of the canal may be low 0.25 cfd, but it is obvious that the section should be lined to prevent extension of land damage.

On the other hand it is possible to have a loss rate which positively indicates the need for lining where no damage to adjacent lands is evident. In this case the loss of water is important.

Seepage rates from canals can vary widely throughout the year. On one ponded canal the seepage varied from 0.58 cfd in the spring to 0.24 cfd in the fall. A variation in rates such as this is not unusual especially where silt deposition or other sealing takes place over a period of time. The causes for seepage variations can be attributed to the factors listed at the beginning of this article.

Sources of Error

Accuracy of loss rates established by the ponding method will depend on the attention given to relatively simple details in preparing for and conducting the tests. Generally speaking, the end of the irrigation season is considered the most appropriate time for making seepage tests. At this time, bank storage has been satisfied and the water table in the adjacent areas has stabilized in elevation so that conditions are more nearly representative of those during the irrigation season.

Because of the time required to refill a pond and to repeat a test, making the test after the irrigation season provides sufficient time for repeat tests. Otherwise with limited time the temptation may be to accept seepage rates established in a single filling. When seepage rates are other than small, this practice could lead to erroneous conclusions concerning the true losses.

Dikes and any turnouts in the pond should be inspected periodically to be sure they are not leaking. If check structures have been used, they should also be inspected to be sure stoplogs and canvas are in place. Leakage around the canvas can usually be averted by timely placement of more fill material at the edges.

Hook or staff gages not provided with stilling wells can yield erroneous readings of water surface levels even when only a light breeze is blowing. Also, it is easy to misread the gage by a full 0.1 foot; but checking the previous reading or comparing loss increments when upstream and downstream gages are used will usually prevent the error from being recorded.

In any pond which shows a rapid drop of the water surface, elevations must be determined frequently. The longer the time interval between readings, the less accurate will be the average wetted perimeter and average water surface widths used in the calculations.

The survey which establishes elevations on all gages is very important. Closed circuits should be used, and the allowable error of closure should be in keeping with the quality of results expected. At some time during the conduct of any test there will probably be a complete absence of a breeze, and the pond water surface will become obsolutely still. A check reading on all gages, and particularly on the hook gages will reveal how well the gages have been set.

When computing the results from field data, many chances for calculator errors will occur. The existence of large errors can be detected by carefully analyzing trends in tabular values.

* * * * *

I. TABLE OF WATER SURFACE WIDTHS

Canal HIGH LINE Pond No. AT STA 116+00 to 124+50

Elevation / Station	Water Surface Widths for Various Elevations							
	1909.4	1909.6	1909.8	1910.0	1910.2	1910.4	1910.6	1910.8
116+00	8.6	9 2	9.7	10.4	10.9	11.6	12.1	12 8
116+50	8.7							
117+00	8.8							
117+50	9.0							
118+00	9.1							
118+50	9.3							
119+00	9.2							
119+50	9 0							
120+00	9.5							
120+50	9.6							
121+00	9.8							
121+50	10.0							
122+00	10.0							
122+50	9.7							
123+00	10.7							
123+50	11.0							
124+00	11.2							
124+50	10.9	11.0	11.1	11.2	13.6	14.1	14.7	15.5
Total	174.6							
Average	9 7	10.1	10.4	10.8	12.2	12 8	13.4	14.3

The figures in this table are used as an illustration. The table is not completely filled out. Interpolate for water surface widths not calculated.

II. TABLE OF WETTED PERIMETERS

Canal HIGH LINE Pond No. At Sta. 116+00 to 124+50

Elevation / Station	Wetted Perimeters for Various Elevations							
	1909.4	1909.6	1909.8	1910.0	1910.2	1910.4	1910.6	1910.8
116+00	11.0	11.6	12.0	12.1	12.3	13.3	15.0	15.5
116+50	11.1							
117+00	11.0							
117+50	11.5							
118+00	11.3							
118+50	11.2							
119+00	11.9							
119+50	12.2							
120+00	12.1							
120+50	11.7							
121+00	11.6							
121+50	11.2							
122+00	11.7							
122+50	11.9							
123+00	12.0							
123+50	11.6							
124+00	12.2							
124+50	12.0	12.1	12.3	13.3	15.0	15.5	16.2	17.4
Total								
Average	11.5	11.8	12.2	12.7	13.9	14.4	15.8	16.4

The figures shown in this table are used as an illustration. Table is not completely filled out. Interpolate for wetted perimeters not calculated.

TABLE III

NOTE: Assume two staff gages and a recorder used on this pond.

SEEPAGE LOSS DATA

Canal HIGH LINE   Hook gages: sta. NONE and sta. ______

Dike: sta. 116+00 and sta. 125+00   Staff gages: sta. 116+50 (S_1) and sta. 124+00 (S_2)   Recorder: LMT

Date	Time	Hook		Staff		Temperature			ADD 1908.38 to STAFF GAGE FOR ELEVATION			Remarks
		H_1	H_2	S_1	S_2	Air	Water					
9/16	9:00AM			2.32	2.32	60°	55°		1910.70			
9/16	3:00PM			2.14	2.13	85°	58°		1910.52			NORMAL W.S. 1910.4 AT STA. 124+50
9/16	11:00PM			1.86	1.86	70°	65°		1910.24			
9/17	9:00AM			1.51	1.51	65°	58°		1909.89			
9/17	5:00PM			1.26	1.25	90°	60°		1909.64			
9/18	1:00AM			1.05	1.04	65°	65°		1909.43			
9/18	9:00AM			2.03	2.05	68°	58°		1910.42			REFILLED POND DURING NIGHT.
9/18	12 NOON			1.94	1.94	85°	61°		1910.32			
9/18	5:00PM			1.78	1.78	90°	64°		1910.16			

IV. TABLE FOR COMPUTING SEEPAGE LOSSES

1	2	3	4	5	6	7	8	9	10	11	12
Date	Time	Elapsed time, hours	Water surface elevation	Drop in water surface feet	Water surface width feet	Average water surface width, feet	Product of Columns 5 & 7	Wetted perimeter, feet	Average wetted perimeter	Product of Columns 3 & 10	Seepage rate cfd $\frac{\text{Col. 8 x 24}}{\text{Col. 11}}$
9/16	9:00AM		1910.70		13.8			15.9			
		6.0		.18		13.55	2.44		15.55	93.4	0.63
9/16	3:00PM		1910.52		13.3			15.2			
		8.0		.28		12.85	3.60		14.55	116.4	0.74
9/16	11:00PM		1910.24		12.4			13.9			
		10.0		.35		11.45	4.01		13.15	131.5	0.73
9/17	9:00AM		1909.89		10.5			12.4			
		8.0		.25		10.3	2.60		12.1	96.8	0.65
9/17	5:00PM		1909.64		10.1			11.8			
		8.0		.21		9.9	2.08		11.65	93.2	0.54
9/18	1:00AM		1909.43		9.7			11.5			
		— REFILL									
/18	9:00AM		1910.42		12.8			14.4			
		3.0		0.10		12.7	1.27		14.2	42.6	0.72 1/
9/18	12N		1910.32		12.6			14.0			
		5.0		0.16		11.75	1.88		13.85	69.3	0.65
9/18	5:00PM		1910.16		11.9			13.7			

BASIC EQUATION:

$$(\text{cfd}) = \frac{\text{Length of Pond x Drop in Water Surface x Average Width of Water Surface x 24}}{\text{Length of Pond x Average Wetted Perimeter x Hours of Run}}$$

1/ Note that an error of 0.01 in gage readings in this calculation would influence the seepage rate 10%. The time interval is too short.

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