PERMEABILITY CHARACTERISTICS OF WATER CONVEYING DITCHES
LOCATED IN IRRIGATED SOILS

by

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INTRODUCTION

In 1962, Kansas had more than one million acres of irrigated farm land. Some thirty-eight thousand acres of this land is served from reservoirs and the balance is served by pumping plants drawing water from wells and streams. Every acre of this land is served by some type of distribution system, either buried pipe lines, aboveground pipe lines, open ditches or combinations of the above. If the same rapid expansion of irrigation in Kansas continues as it has in the past five years, there will be another half a million acres under irrigation by 1970.

An ever-increasing need for conservation of water in areas where water is needed for irrigation demands that water losses be minimized wherever possible. Inefficiency in the conveyance of water in irrigation canals and ditches has long been a recognized water-wasting problem. Various programs and developments have been initiated by private companies and Federal agencies to find ways of eliminating excessive conveyance losses in irrigation canals and ditches. As an initial part of any program, it is important to know the amount of the losses and where the losses are occurring. Seepage losses usually represent the major portion of canal conveyance losses. In Kansas, some work has been done by the Bureau of Reclamation on seepage losses from their canal systems. Most of this work has been confined to the main canal sections and the bed material on which the canal is built. There has been little,

if any, work done to determine what the seepage losses are on the individual farm where the water is actually used.

PURPOSE

It has been suggested that a more thorough investigation be made of seepage losses in Kansas. This investigation would be confined to small irrigation ditches on individual farms located within a major soil type. The results of this investigation would have a two-fold meaning. They would not only indicate what soils had a high rate of seepage losses, but would also serve as a yardstick to measure how extensive a ditch lining program the individual could afford to undertake. These seepage losses represent additional costs to the individual concerned, and by reducing the seepage to a minimum, these costs could be put to a more profitable use in his irrigation program. Also of concern, is the fact that water is fast becoming a critical item in some areas of the state. Where this is happening, the individuals using water for irrigation are interested in obtaining better water use efficiency by controlling seepage losses.

REVIEW OF LITERATURE

Seepage has been defined by Tolman (10) as the movement of water into or out of the ground. This definition differs from that of Meinzer (4) in that the word "movement" replaces "percolation", which refers specifically to the slow movement

of water through small passages among the particles that make up soil or rock. In this thesis, the author uses the word "seepage" to mean movement of water into or out of irrigation channels through interstices in the bed material.

There are many factors known to have a definite effect on seepage rate, the principal ones being:

1. Characteristics of the soil of the canal bed.

2. Length of time the canal has been in operation.

3. Depth to ground water.

4. Amount of sediment contained in the water.

5. Depth of water in the canal.

6. Temperature of the water and of the soil.

7. Percentage of entrained air in the soil.

8. Capillary tension in the soil.

9. Barometric pressure.

Since all of these factors are acting simultaneously, and some of them tend to counteract each other, it is difficult to segregate the effect of any one of them. Because of the many variables involved and the complexity of their relations, no satisfactory formula for computing seepage has ever been developed.

Seepage takes place under the combined influence of gravity and soil moisture-tension gradient. In a dry ditch, when water is first applied, the force of the moisture-tension gradient may exceed that of gravity, but as the soil approaches saturation the force arising from the moisture-tension gradient

becomes small. Consequently, the major seepage losses can be attributed to forces caused by gravity.

The factor most important in determining rate of seepage is the permeability of the material forming the bed of the canal. Permeability is a porous medium's capacity for transmitting water. It is influenced both by pore size and by percentage of pore space, or porosity, but as pore size decreases permeability decreases in approximately the same ratio as the square of pore diameter (10). This is the reason for the relative imperviousness of clays which have high porosity but very small pore diameter. The permeability of gravel depends on the size and the size gradation of the gravel particles. Laboratory tests by the U. S. Geological Survey have shown that course gravel may transmit water 450 million times as fast as clayey silt (5). The wide range of possible seepage losses is apparent from this fact.

Seepage rate is determined in part by the head available to drive the water through the soil. This factor depends not only on the depth of water in the canal, but also the depth to ground water and the nature of the material composing the canal bed. In a study of water spreading for underground storage, Mitchelson and Muckel (6) observed that the seepage rate decreased materially when the ground-water level reached the elevation of the surface of the spreading area. An increase in rate occurred while the ground-water level was dropping below the elevation of the spreading-area surface, but this

trend disappeared when the ground-water level had dropped a few feet farther.

If the soil underlying an irrigation canal bed is less permeable than the bed, water lost by seepage spreads laterally as it percolates downward. In more permeable soil, water lost by seepage moves downward as a film of moisture on soil particles in the zone directly beneath the canal. In this case a tension gradient occurs in the unsaturated soil and supplements the force of gravity in causing the downward movement. The nature of the flow under these conditions has been confirmed through tests conducted by Lauritzen and Israelsen (3) on a model canal section.

Because of the many factors involved and the interrelations of these factors, it is difficult to determine what part of the seepage from a canal is due to the depth of water in the canal. Tests previously made by the Division of Irrigation and Water Conservation on canals (8) showed that although seepage decreases as depth of water decreases, the two changes are not directly proportional. Lack of correlation between depth of water and seepage rate has been reported also by Lane as cited by Tolman (10). Recent laboratory tests by Warnick (12) in a tank 5 feet in diameter showed that seepage generally decreased as depth decreased, but there were anomalies in the data.

Time is a factor in rate of seepage from canals, because of changes that occur in bed material with the lapse of time. Water moving into the soil carries small particles in suspension

and deposits them in pore spaces, and this gradually reduces
the soils porosity. Temperature is another factor affecting
seepage rates. With an increase in temperature the viscosity
of the water is lowered, thus increasing seepage flow. At the
same time the vapor pressure in the soil is increased with a
rise in the temperature, thus tending to decrease seepage flows.
Thus it can be seen, the effect of temperature is nearly
canceled in the total seepage flows.

Sodium salts in water tend to puddle clay soils thus
reducing seepage rates, whereas calcium or sulfur in the water
tend to make soils high in sodium more porus.

Although no satisfactory formula has ever been devised for
computing seepage, certain fundamental relations of the factors
influencing seepage rates have been definitely established.
According to Darcy's law as stated by Robinson and Rohwer (7),
the velocity of flow through water-bearing materials is
directly proportional to the head consumed and also to the
permeability of the material. This law is generally assumed to
apply to flow through all saturated water-bearing materials in
which the pores are of capillary size and the flow is laminar.
It applies also to seepage. Its validity has been confirmed
by numerous experiments.

In terms of factors involved in the study of seepage,
Darcy's law is expressed by the formula

$$Q = KIA,$$

in which Q is the quantity of water lost in unit time, K is the

coefficient of permeability, I is the hydraulic gradient, and A is the wetted area of the canal bed and banks. This formula may also be expressed in terms of the head available, as

$$Q = \frac{KHA}{L}, \text{ where } I = \frac{H}{L},$$

in which Q, K, and A have the same significance as before, H is the total head producing seepage, and L is the length of the column of material through which seepage is taking place under head, H.

In these formulae K, the permeability coefficient, is the measure of all properties of the soil composing the bed of the canal that affect the seepage rate. Accurate permeability values can be obtained by directly measuring the flow through the material by means of permeameters, and by analyzing discharge and drawdown data from pumped wells (13). These methods provide useful information, but they do not measure permeability in critical areas of a canal bed, which determines the seepage rate. Furthermore, the material in the bed of a canal is not uniform, and results of a test of permeability in one part of the bed may differ materially from those of a similar test in another.

The area within a section of a canal from which seepage is occurring can easily be determined from the wetted perimeter and the length of the section. However, the factors H and L in the second equation are interrelated; L affects H. The effective head can be determined by measuring the hydrostatic

head in the soil at distance L beneath the bed of the canal and subtracting it from the head due to the depth of water in the canal. This procedure presents many problems and is usually not attempted.

Although Darcy's law is unsatisfactory for computing seepage, it is useful in showing how the various factors that affect the seepage rate are related. Seepage is directly proportional to each of the factors permeability, hydraulic gradient, and area. An error in any one of these factors affects a seepage measurement in like proportion.

METHOD AND PROCEDURE

To accomplish the purpose of this investigation, a seepage loss measuring program was organized to measure the seepage losses in irrigation ditches on individual farms. Of major interest were soils having a large number of irrigated acreage.

It was decided that to gain the most information in the shortest possible time, a meeting would need to be held between the author and personnel from the Soil Conservation Service. The purpose of this meeting was to gain knowledge of the major soils in Kansas that have a large number of irrigated acres, and where these soils were located within the state. The soils chosen for this investigation as a result of this meeting were:

1. Richfield Silt Loam
2. Ulysses Silt Loam
3. Dalhart Fine Sandy Loam

After selecting the soils for this investigation, the area within the state where these soils are located was delineated on a map. Farmers growing and irrigating crops within this area were contacted and asked if seepage investigations could be conducted on their farms. Fig. 1 shows the approximate location of the sites selected, and Figs. 2 through 5 in the appendix show the exact locations and soils of the test sites. Figs. 2 through 5 are copies of the U. S. Department of Agriculture, Soil Conservation Service soil maps as they were mapped in the field.

After the sites for the investigation had been selected, the next step was to decide what method of determining seepage losses would be used. Various methods have been developed for measuring seepage losses in the field or in the laboratory. Some of these methods yield results in terms of average seepage for a section of a canal, others give the seepage rate for a small unit of area or merely furnish information as to the permeability of a sample of the canal bed material. When methods are used that yield information as to permeability only, additional observations must be made to determine the hydraulic gradient. The difficulties encountered here have already been explained. The five commonly used methods of determining seepage are as follows:

1. Inflow-Outflow
2. Ponding
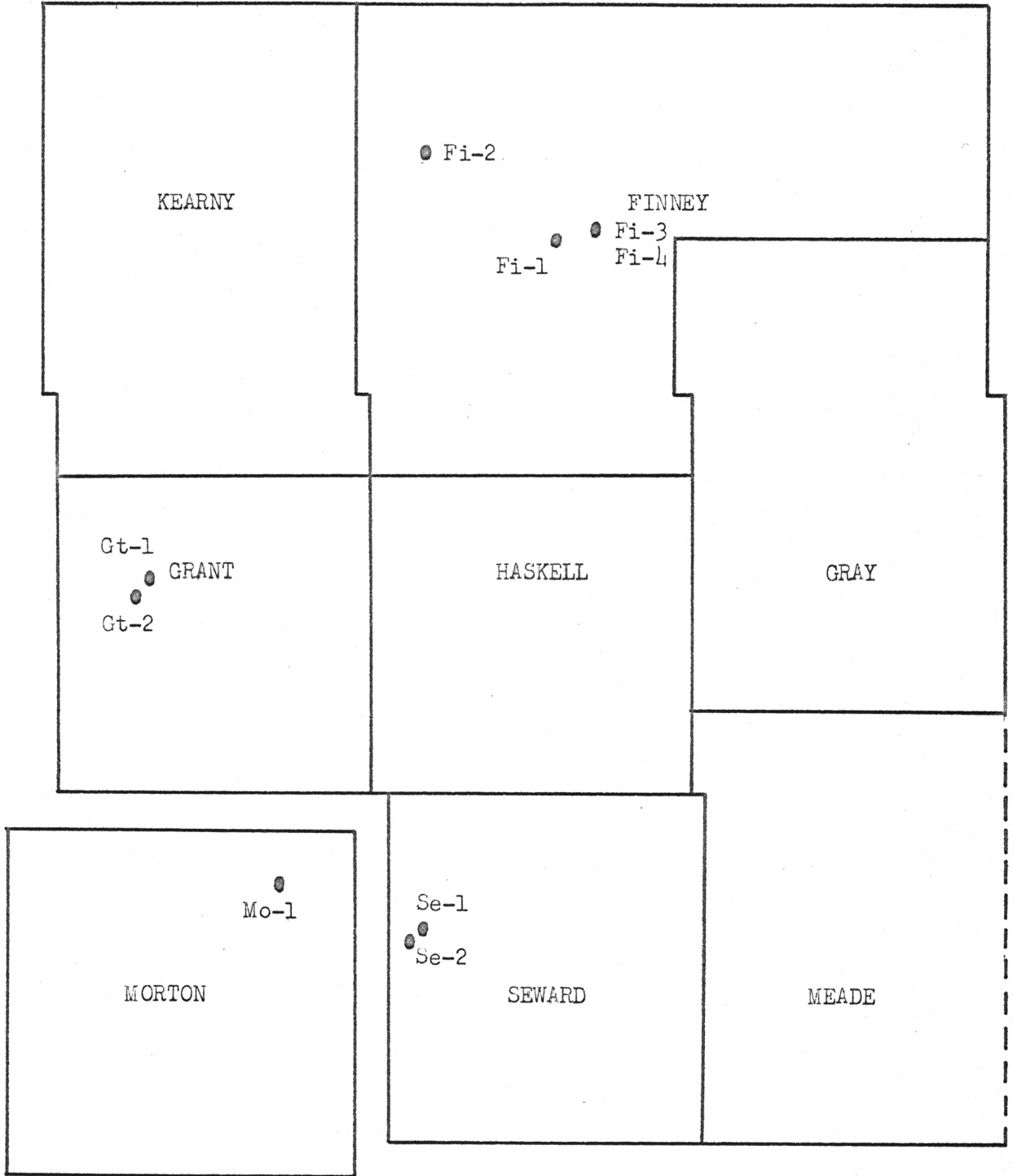3. Seepage-Meter
4. Well-Permeability
5. Laboratory Permeability

Fig. 1. Map showing the approximate location and test number of the sites selected for this investigation in Southwestern Kansas.

There are some special methods that are considered too cumbersome to be attempted in this type of investigation. They are:

1. Adding radioactive isotopes to water and tracing the seepage.

2. Measurement of changes in electrical resistance of soil due to water and salt content.

3. Piezometric survey to determine flow lines and pressure distribution in the soil under a canal.

Of the five methods listed, the ponding method is the most accurate and least susceptable to error, but because of the procedure used, it is not always possible to use in all cases. Because of the need to use a consistent method throughout the investigation, it was decided to use the Inflow-Outflow method for determining the seepage losses. One reason for this decision was that usually the tests were conducted while the farmers were irrigating. Most of them were reluctant to stop irrigation while the tests were being made, thus a method of checking seepage had to be chosen with this in mind. The Inflow-Outflow measuring devices could be installed in the irrigation ditch while water was in the ditch. Another reason for using the Inflow-Outflow method was that generally a very small portion of an irrigation ditch has standing water in it, while the major portion of the ditch is used to convey the water. Since one of the primary objectives of this investigation was to determine water losses under normal operating conditions, it was thought that the Inflow-Outlow would give more realistic results of actual conditions. Some investigators

have stated that the difference in seepage rates of still water
and flowing water is probably inconsequential in view of errors
associated with flow measuring devices.

The seepage-meter was not considered for this investigation
because it has not been perfected to the point of giving
accurate results. The seepage-meter gives results as to the
magnitude of losses, rather than accurate measurement of the
losses. Another disadvantage of the seepage-meters is that they
must be installed with great care, so as not to disturb the
canal bed around the meter. One advantage of the seepage-meters
is that one can make quick determinations of seepage losses in
a section of canal to see if there is need for more accurate
measurements.

The well-permeability and the laboratory permeability
measurements furnish information as to the permeability of a
sample of the canal bed material. When permeability is measured,
additional measurements must be made to determine the hydraulic
gradient. At best, these two methods will only give an indi-
cation of magnitude of seepage losses and are generally used
only by a designer to determine if canal linings should be
considered during construction of large canals.

Once the method and locations had been selected, all that
remained was to select suitable measuring devices. Since the
sites were widely scattered throughout the Western part of the
state, the water measuring devices would need to be readily
mobile. Also, ease of installation and removal was a factor.

Other factors to be considered were:

1. Variable ditch grade and size from site to site.

2. Small, shallow ditches, thus limiting the amount of head available to cause flow through structures.

3. Difficulty encountered in cutting off flow around and under structures while installing them in flowing water.

After considering all of the above factors, it was decided that a bulkhead with a submerged orifice which could be driven into the ditch banks and bottom would fulfill all the requirements. Because of the shallowness of the ditches, the orifice size had to be such that the head causing flow through the orifice would not overtop the ditch berms on the upstream side of the bulkhead. Since flows encountered would vary from 800 gallons per minute to 2,000 gallons per minute, several sizes of orifice plates were needed. Based on this information, orifice plates were machined from 1/4-inch aluminum plate. Two sizes, 12-inch and 16-inch diameters, were made and calibrated against a standard water measuring device in the hydraulics laboratory of Kansas State University. These two sizes were selected because they could accommodate the range of flows encountered and still not exceed 5-inches of head loss through the orifice. The bulk-heads were fabricated from 14-gage galvanized sheet iron and 1/8-inch by 2-inch by 2-inch angle iron in such a manner that they could be driven into place with a sledge hammer. Hook gages were fabricated and mounted on the bulkhead so that the head loss across the orifice could be read directly. Plate II shows the general construction of the bulkhead with orifice and head measuring device installed.

EXPLANATION OF PLATE I

Fig. 1. Device used for taking cross-section profiles of the
         irrigation ditches.

Fig. 2. Typical installation of evaporation pan in an
         irrigation ditch.

Fig. 3. Close-up of evaporation pan showing the stilling
         basin and water-level measuring device.

PLATE I
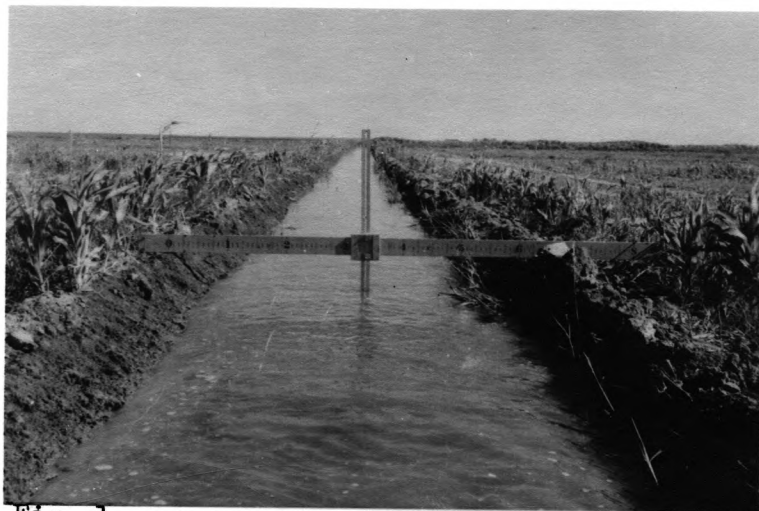
Fig. 1
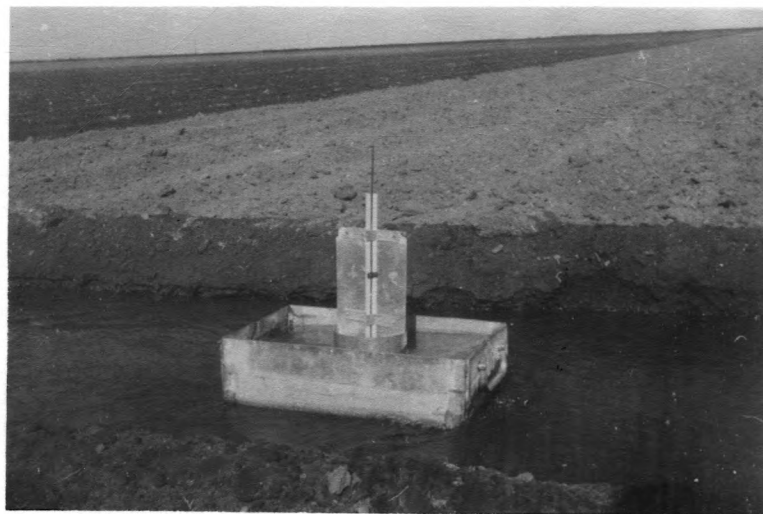
Fig. 2
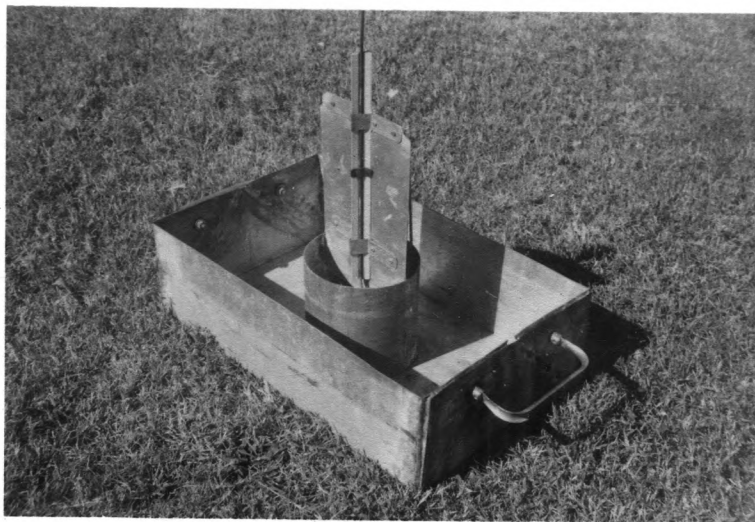
Fig. 3

EXPLANATION OF PLATE II

Fig. 1.　Overall construction of the bulkhead with the orifice
　　　　　plate and head loss measuring device installed.

Fig. 2.　Typical installation of bulkhead in irrigation ditch.

Fig. 3.　Close-up view of head loss measuring device. The
　　　　　left hand hook shaft is marked in increments of 0.01
　　　　　inch. A level vial is mounted on the main frame of
　　　　　the device for leveling the unit after installation.

PLATE II
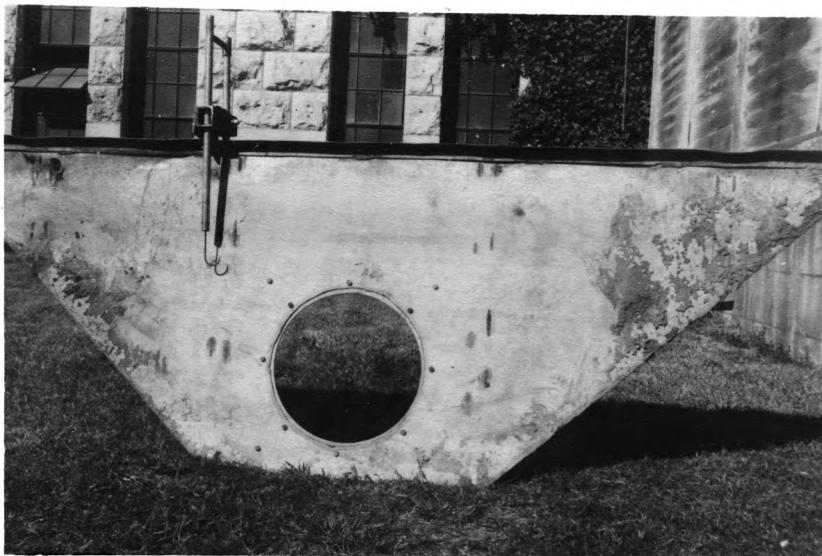
Fig. 1

Fig. 3

Fig. 2

Since the primary interest was to measure seepage losses through the soil only, some method of measuring loss by evaporation needed to be developed. This was accomplished by fabricating an evaporation pan that could be installed in the irrigation ditch, with a suitable measuring device for determining the water actually lost from the pan. Thus, knowing the evaporation rate and the surface area of the ditch section between the two measuring stations, the total losses due to evaporation could be calculated and deducted from the measured gross loss. The temperature of the water in the pan and ditch was noted and recorded. Plate I shows the general construction of the evaporation pan and measuring gage.

After the flow measuring devices were installed in the ditch a period of time, usually 2 to 3-hours, was allowed to pass before any readings were taken. This was to allow flow in the ditch to become stabilized after disruption from installing the bulkheads. During this time, the evaporation pan was installed in the ditch and the initial reading taken. A standard 8-inch rain gage was set and used to measure any rain falling during the test. After flow had stabilized, initial readings were taken on the inflow and outflow measuring stations. These readings were checked every hour to see that there had been no change in quantity of water flowing past each station. The inflow and outflow values reported in Table 1 are the mean value of the average hourly rate of flow of water into or out of the test section. Duration of all tests was at least a 24-hour period.

Wind velocity measurements were made periodically through-out the test period and these are reported in Table 5 of the Appendix. Wind velocity measurements were made at an elevation of three feet above the water's surface. Other data taken and recorded were air temperature, relative humidity, and barometric pressure.

At tne end of the 24 hours, or sooner in the case of five of the tests, the loss from the evaporation pan was measured and recorded. The evaporation losses as reported in Table 1 are the average hourly rate during the test period.

Other observations made during the investigation were relationship of the ditch line direction to wind direction, the proximity of the saturated zone in the soil profile to the ditch, and whether the water surface in the ditch was above or below original ground surface.

RESULTS

Location and Classification

The data in this investigation were obtained during the summer of 1963 at existing irrigation systems in four South-western Kansas counties. Tests were conducted on seven different farms and with three different soils.

The approximate location of the test sites is shown in Fig. 1. Each test was assigned a code number consisting of an abbreviation of the county in which it was located, and a number according to the order performed in that county.

Table 1. Summary of losses due to seepage and evaporation.

Test	Code No.	Location	Soil (2)	S.C.S. Desgn.	Length ft.	W.P. (3) ft.	W. (3) ft.	Inflow into Test Section g.p.m.	Outflow from Test Section g.p.m.	Loss from Test Section g.p.m.	Evapor. from Test Section g.p.m.	Net Loss from Test Section g.p.m.	Loss Factor ft/da	Net Seepage Losses Per 1000 Feet of Ditch c.f.s.	g.p.m.	ac.ft/da	percent	Net Loss in g.p.m. per 1000 Square Feet of Wetted Surface Area
1	Fi-1	S3;T24S;R32W	R-sl	M3-A	400	3.68	3.13	316	301	15	0.4	14.6	1.9	0.08	36.5	0.16	4.6	9.9
3	Gt-2	S18;T28S;R38W	R-sl	M3-A	800	3.85	3.00	871	779	92	0.5	91.5	5.7	0.25	114.4	0.50	10.5	29.7
9	Mo-1	S27;T31S;R40W	R-sl	M3-A	1000	5.01	4.51	848	803	45	1.1	43.9	1.7	0.10	43.9	0.20	5.2	8.8
2	Gt-1	S8;T28S;R38W	U-sl	M44-A	800	3.20	2.30	675	645	30	0.4	29.6	2.2	0.08	37.0	0.16	4.4	11.6
4	Fi-2	S1;T23S;R34W	U-sl	M44-A	1000	4.30	3.50	993	971	22	0.4	21.6	1.0	0.05	21.6	0.10	2.2	5.0
5	Fi-3	S31;T23S;R31W	U-sl	M44-A	800	6.70	5.50	1030	993	37	0.8	36.2	1.3	0.10	45.3	0.20	3.5	6.8
6	Fi-4	S31;T23S;R31W	U-sl	M44-A	800	6.70	5.50	993	973	20	0.7	19.3	0.7	0.05	24.1	0.10	1.9	3.6
7	Sw-1	S27;T32S;R34W	D-fsl	S4-B	600	6.24	5.54	1349	1321	28	0.6	27.4	1.4	0.10	45.7	0.20	2.0	7.3
8(1)	Sw-2	S32;T32S;R34W	D-fsl	S4-A	500	5.96	4.85	1003	993	10	0.2	9.8	0.6	0.04	19.6	0.08	1.0	3.3
*	----	Stevens County	D-lfs	------	600	5.40	----	624	566	58	---	58.0	3.4	0.22	96.7	0.44	9.3	17.9
*	----	Stevens County	R-sl	------	800	4.13	----	422	382	40	---	40.0	2.3	0.11	50.0	0.22	9.5	12.1
*	----	Stevens County	U-sl	------	800	4.98	----	601	588	13	---	13.0	0.6	0.04	16.3	0.08	2.2	3.3

*Data taken from Irrigation Ditch-Water loss studies, Soil
 Conservation Service, Stevens County, August 11 - 13, 1959.

(1) Average of three replications   (3) W.P. = Wetted Perimeter in feet

    R = Richfield   W. = Surface Width in feet

    U = Ulysses   g.p.m. = Gallons per minute

    D = Dalhart   c.f.s. = Cubic feet per second

    sl = silt loam

    fsl = fine sandy loam   ac.ft. = Acre-Feet

    lfs = loamy fine sand   (4) "Loss Factor" is the depth of Seepage in feet per day

Inasmuch as conditions varied among tests as to soil type, rate of flow of water, wetted perimeter, length of ditch, etc., the only criteria that the data obtained can be analyzed is to consider each test individually and without relation to other tests. Because of variation in length and wetted perimeter of the different test sections in the field, it was decided that some common unit would need to be derived for better representation of the comparative losses. The units considered logical for this comparison were gallons per minute per 1000 square feet of wetted area. Another term used for the comparison of seepage rates, which has been called "loss factor", is actually the permeability of the soil. The "loss factor" is defined as the equivalent depth of water lost through each square foot of wetted area during a 24-hour period (8). It was computed by the following method: The rate of seepage expressed in "cubic feet per second" is multiplied by the number of seconds in a 24-hour period which gives the total number of cubic feet of water lost per 24-hour period. The total loss is then divided by the number of square feet in the "total wetted area" which gives the depth of water in feet, lost through each square foot of wetted area. The latter term is the "loss factor". Thus, each test can be compared with the other tests and these units can be carried to other ditches, on similar soil, whose dimensions are known.

The actual length of each test section or "reach" of ditch was measured with a steel tape along with the surface width and

"wetted perimeter". The width and wetted perimeter are averages of several measurements taken along the reach of ditch being tested.

In general, the ditches used in this study were fairly uniform in construction, so that the average value obtained is representative of local conditions for each test. The total wetted area of each ditch was then obtained by simply multiplying the length of reach by the average wetted perimeter. The seepage losses as presented are the net loss in gallons per minute, after evaporation is deducted, multiplied by 1,000 and divided by the wetted area in square feet.

Soil classifications were made by the Soil Conservation Service soil scientists in the field. The series, type and the S. C. S. soil designations are those which were reported by the Soil Conservation Service. The author prepared a summary report, from published Soil Survey reports, of the three soils covered by this study which are presented in Figs. 6, 7 and 8.

The Tests and Results

A study of the seepage losses from ditches located in the various soils, classified by series and type provided the results as shown in Table 2.

The Dalhart series consists of deep, dark-colored, well-drained sandy soils of the upland. The soils occur on nearly level and sloping topography. They have a sandy surface soil and sandy clay loam subsoil. The parent material is sandy and was deposited by wind. These soils developed under a cover of tall and mid grasses.

A_{1p} Horizon (0 - 4")

    Grayish-brown fine sandy loam or loamy fine sand; some weak granular structure; consistence is soft when dry, very friable when moist; noncalcareous.

A_1 Horizon (4 - 8")

    Dark grayish-brown fine sandy loam; moderate, medium, granular structure; consistence is hard when dry, friable when moist; a few worm casts; noncalcareous.

B_{21} Horizon (8 - 20")

    Dark grayish-brown fine sandy loam; moderate, granular structure; consistence is very hard when dry, friable when moist; a few worm casts; noncalcareous.

B_{22} Horizon (20 - 30")

    Brown sandy clay loam; mainly moderate, medium, granular structure but some weak, sub-angular blocky; consistence is very hard when dry, friable when moist; a few worm casts; noncalcareous.

B_3 Horizon (30 - 42")

    Brown sandy clay loam; moderate, medium, granular structure; consistence is hard when dry, friable when moist; a few worm casts; noncalcareous.

C Horizon (42 - 48")

    Brown fine sandy loam; porous; massive; consistence is soft when dry, very friable when moist; calcareous.
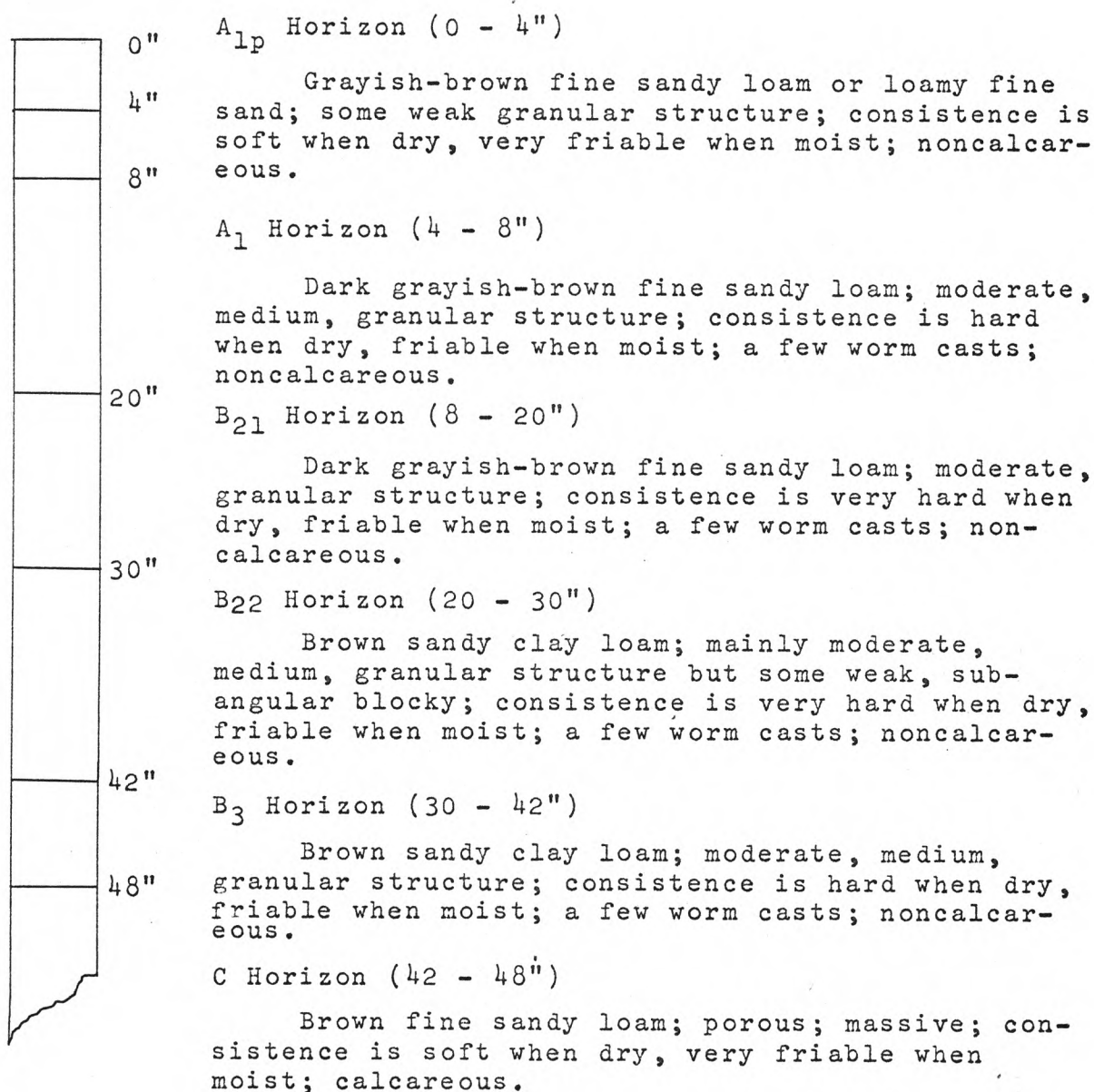
Fig. 6. Profiles and description of the soils of the Dalhart series.

The Ulysses series consists of deep, moderately dark-colored soils of the upland. These soils occur on nearly level, gently sloping, and sloping areas. They have a silty surface soil and subsoil. The parent material consists of silty sediments or loess. These soils have developed under a cover of short and mid grasses.

A_{1p} Horizon (0 - 6")

0"

    Dark grayish-brown silt loam; weak, fine, granular structure; consistence is soft when dry, friable when moist; noncalcareous.

6"

B_2 Horizon (6 - 13")

    Dark grayish-brown silt loam or silty clay loam; moderate, medium, granular structure; consistence is slightly hard when dry, friable when moist; a few worm casts; noncalcareous.

13"

B_{3ca} Horizon (13 - 23")

    Pale brown silt loam; weak to moderate, medium, granular structure; consistence is slightly hard when dry, friable when moist; many worm casts; calcareous.

23"

C_{ca} Horizon (23 - 43")

    Very pale brown silt loam; massive and porous; consistence is lightly hard when dry, friable when moist; calcareous, with about 5 percent of the layer made up of soft concretions of calcium carbonate.
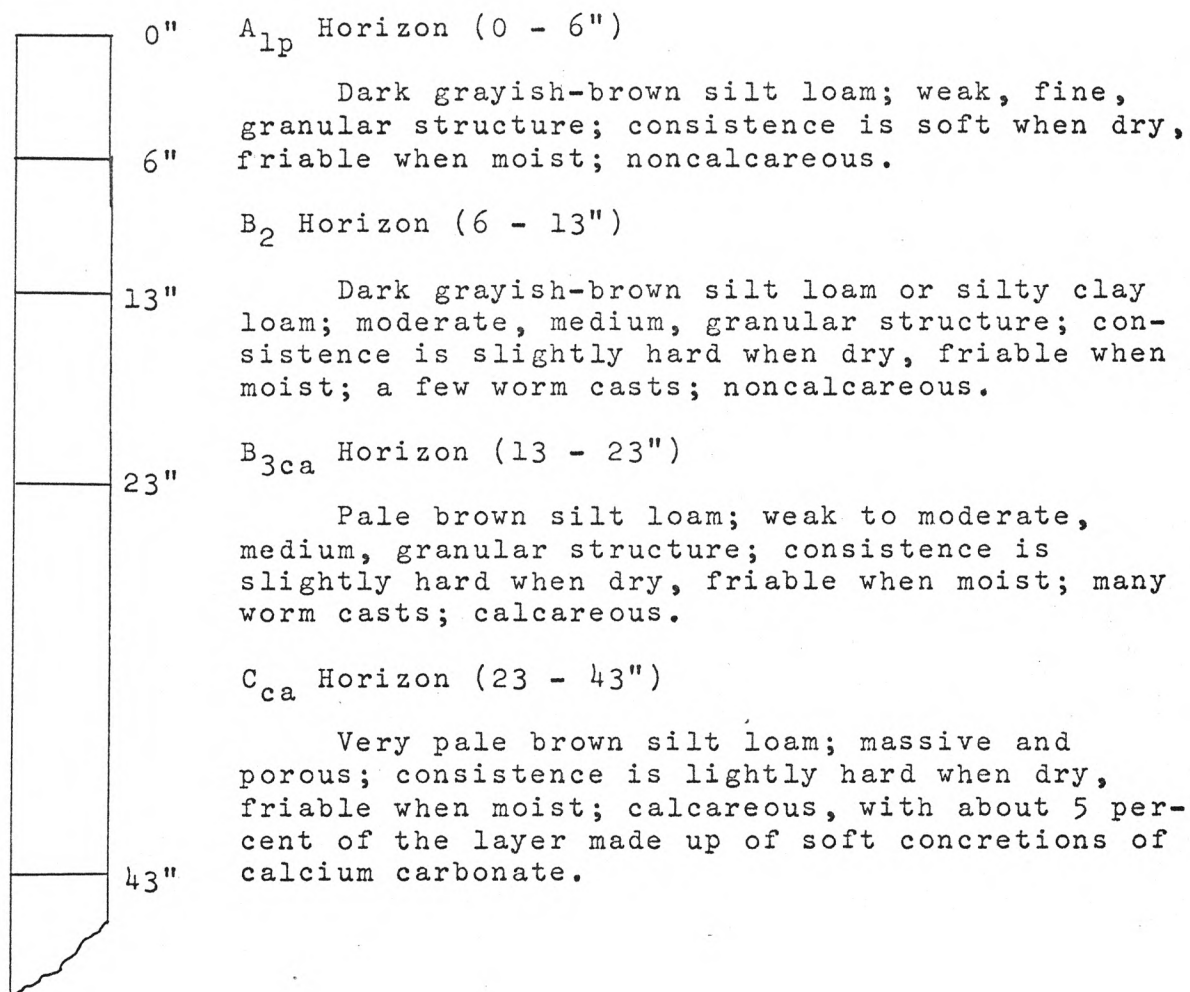
43"

Fig. 7. Profile and description of the soils of the Ulysses series.

The Richfield series consists of deep, dark-colored
soils of the nearly level upland. These soils have a clayey
subsoil; the surface soil, however, varies in texture. The
soils are well drained. Their parent material consists of
loess or similar silty sediments. These soils have developed
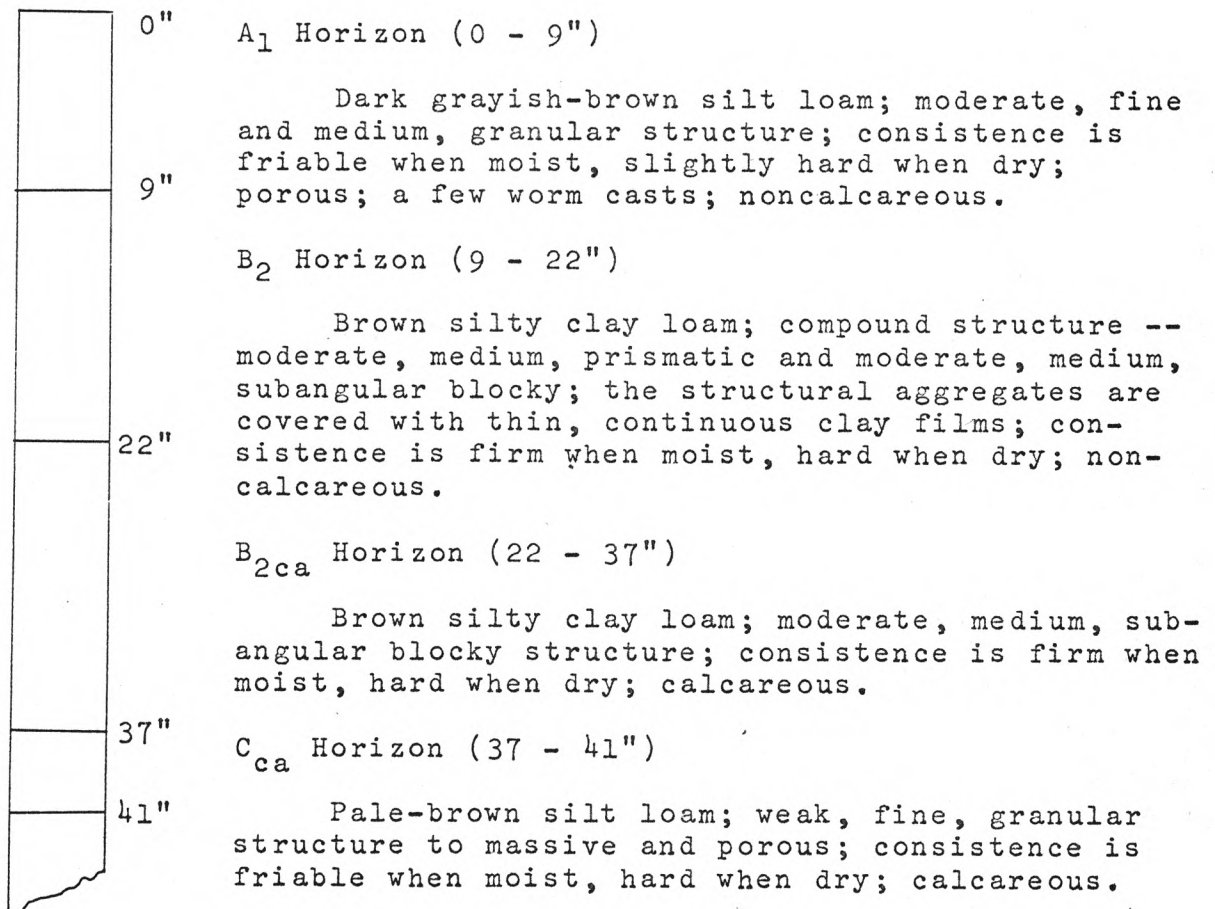under a cover of short and mid grasses.

0" A_1 Horizon (0 - 9")

           Dark grayish-brown silt loam; moderate, fine
      and medium, granular structure; consistence is
      friable when moist, slightly hard when dry;
9"   porous; a few worm casts; noncalcareous.

      B_2 Horizon (9 - 22")

           Brown silty clay loam; compound structure --
      moderate, medium, prismatic and moderate, medium,
      subangular blocky; the structural aggregates are
      covered with thin, continuous clay films; con-
22"   sistence is firm when moist, hard when dry; non-
      calcareous.

      B_{2ca} Horizon (22 - 37")

           Brown silty clay loam; moderate, medium, sub-
      angular blocky structure; consistence is firm when
      moist, hard when dry; calcareous.

37" C_{ca} Horizon (37 - 41")

41"   Pale-brown silt loam; weak, fine, granular
      structure to massive and porous; consistence is
      friable when moist, hard when dry; calcareous.

Fig. 8.   Profile and description of the soils of the
          Richfield series.

Table 2. Summary of results of seepage investigations.

Soils Series and Type	No. of Tests	Average Loss per 1000 ft.	Range of Loss per 1000 ft.	Average Loss Factor ft. per da.
Richfield sl*	4	7.5%	4.6 - 10.5%	2.9
Ulysses sl*	5	2.8%	1.9 - 4.4%	1.2
Dalhart fsl	2	1.5%	1.0 - 2.0%	1.0
Dalhart lfs*	1	9.3%	9.3%	3.4

*Includes data taken from Irrigation Ditch-Water loss
 studies, Soil Conservation Service, Stevens County,
 August 11 - 13, 1959.
 sl - Silt Loam, fsl - Fine Sandy Loam, lfs - Loamy Fine Sand.

Percentage loss of water by seepage has very little meaning when comparing seepage losses, because ditches vary so much in their individual wetted perimeters. This factor is the principal cause of the wide variation in percentages. The depth of water in the ditches contributes to the variation also.

A more meaningful comparison can be made by the use of the "loss factor" since this factor represents the 24-hour loss of water as a depth through each square foot of wetted area (8). The variation in wetted perimeters is thus eliminated as a major variable. Whenever the loss factor exceeds the value of one foot, seepage is considered serious; whenever it exceeds four feet, it is considered to be exceedingly serious. Whenever the loss factor exceeds one foot, it is an indication that ditch linings or pipe should be considered with the cost of the lining or pipe compared to the savings and return from the water conserved. Whenever the loss factor exceeds four feet, ditch linings and

pipe can nearly always be shown to be a profitable investment, both from the savings in water pumped and in what the conserved water will produce in crops (1). If these standards are applied to the average loss factors shown in Table 2, ditch linings or pipe should be considered for all soils tested. This is especially true for the Richfield and Dalhart loamy fine sand.

A comparison of Tests 5 and 6 will show that losses from an elevated ditch are about 50 percent greater than a regular grade ditch in the same soil type. The ditch for Test 6 is a continuation of the same ditch for Test 5. These two tests were conducted simultaneously.

It was found that evaporation from the surface of an irrigation ditch is quite variable from location to location. One particular factor was found to affect evaporation more than any other. This factor was the relationship of the wind direction to the direction of the irrigation ditch. When the irrigation ditch line was parallel to the wind direction, evaporation was higher than when the ditch line was perpendicular to wind direction. Another factor that had some bearing on evaporation rate was the proximity of growing crops to the irrigation ditch line. When an irrigation ditch line was perpendicular to wind direction and a growing crop was located on the windward side of the ditch, evaporation was least. If the ditch line was parallel to wind direction and located in an open area, evaporation was greatest.

Evaporation could be controlled somewhat by the location of an irrigation ditch, but usually topography is the controlling factor in ditch location and direction. Where a choice can be made, some thought should be given to the above factors, and the ditch located where evaporation losses will be the least.

The proximity of the saturated zone to the irrigation ditch was found to follow very closely to what was said at the beginning of this thesis. If the soil underlying the irrigation ditch was uniform in texture, the saturated zone was generally found to be a rectangular area immediately below the ditch itself, with very little lateral movement. On the other hand, if the soil underlying the irrigation ditch was less permeable than the ditch bed, there was considerable lateral movement of the water in the saturated zone. In some cases there was free water standing on the surface of the ground several feet from the ditch itself.

Estimating Losses

A method for estimating the magnitude of losses within a given irrigation system makes use of measured seepage losses found in Table 1.

From Table 1, the average measured seepage loss from a Richfield silt loam is 20 gallons per minute per 1000 square feet of wetted surface area. Estimating losses from

a 2600-foot irrigation ditch, located in a Richfield silt
loam soil, and having a wetted perimeter of 4 feet, would
involve the following equation:

$$T.L. = \frac{(K)(WP)(L)}{1000}$$

Where:

T.L. = Total loss in gallons per
minute.

K = Seepage loss in gallons per
minute per 1000 square feet
of wetted surface area.

WP = Wetted perimeter in feet.

L = Length of ditch in feet.

Then:

$$T.L. = \frac{(20)(4)(2600)}{1000}$$

T.L. = 208 gallons per minute
(or 0.92 acre-feet per day)

From the above computation, it may be shown that for
every 2600 feet of ditch located in Richfield silt loam, with
the above dimensions, one could expect to lose 0.92 acre-feet
of water for every 24 hours of operation.

The "K" value used in the above equation was the average
measured seepage loss of a Richfield silt loam. Factors
that control the value of "K" are:

1. Characteristics of the soil of the ditch bed.

2. Length of time the ditch has been in operation.

3. Depth to ground water.

4. Amount of sediment contained in the water.

5. Depth of water in the ditch.

6. Temperature of the water and of the soil.

7. Percentage of entrained air in the soil.

8. Capillary tension in the soil.

9. Barometric pressure.

These factors are all acting simultaneously, and some of them tend to counteract each other. Because of the many variables and the complexity of their relations, it is easy to understand why no satisfactory formula for computing seepage has ever been developed.

Table 6. Average "K" values for Richfield silt loam, Ulysses silt loam and Dalhart fine sandy loam.

Soil	K gallons per minute per 1000 sq. feet of wetted surface area
Richfield silt loam	20.0
Ulysses silt loam	6.0
Dalhart fine sandy loam	5.3

Another method for estimating the magnitude of losses within a given irrigation system has been suggested by Dell G. Shockley (9). Shockley states:

Our procedure is to measure the losses in selected reaches of the canal system. We attempt to secure measurements representative of the various soil and geologic conditions traversed by the canals. Measurements are made under whatever flow conditions exist at the time of measurement.

The loss measurements are then converted to cubic feet per square feet per 24 hours. This is the value of seepage in 24 hours divided by the wetted area of the canal (average wetted perimeter times the length of the measured canal section). This gives us a seepage loss value for a given canal with a given flow and flow depth (designated as P).

Since the seepage loss value P only applies to specific canal section and depth measured, we convert to a unit-head seepage loss (R_u) by dividing P by the average hydraulic radius (r) (11). This value, which is in units of cubic feet per square foot per 24 hours per unit depth, can be used to transpose seepage losses from one canal flow to another canal constructed in similar material.

As with cylinder infiltrometer studies, a number of measurements must be made in order to determine average R_u values for the representative canal reaches. We have used as few as three measurements but think that more than that usually should be made.

After R_u values have been determined we apply them to the particular channel sections and flows that pertain or are expected to pertain in the system being analyzed.

Following are the factors and formulae of importance in these analyses:

1. Symbols:
   Q_1 = Inflow into the canal section in cubic feet per second.
   Q_2 = Outflow from the canal section in cubic feet per second.
   L = Length of the canal section in feet.
   p = Wetted perimeter of canal section in feet.
   r = Hydraulic radius of canal section in feet.
   P = Seepage loss for a given canal flow and depth in cubic feet per square foot per 24 hours (or feet per day).
   R_u = Unit head seepage loss for a given canal material in cubic feet per square foot per 24 hours per unit depth.

2. Formulae:

$$P = \frac{(Q_1 - Q_2)\ 86,400}{pL}$$

$$R_u = \frac{P}{r}$$

3. Seepage Loss Groupings:
The following is a suggested grouping of
seepage losses in canals:

			R_u
Slow	1.	Very slow	Less than 0.10
	2.	Slow	0.10 to 0.40
Moderate	3.	Moderately slow	0.40 to 1.60
	4.	Moderate	1.60 to 5.00
	5.	Moderately rapid	5.00 to 10.00
Rapid	6.	Rapid	10.00 to 20.00
	7.	Very rapid	20.00 and over

Mr. Shockley goes on to state that they do not know how
to tie the above values to soil types as they did not have
enough experimental data to make an analysis.

Table 3.   Average R_u values for tests in this investigation.

Test No.	Soil	P ft./day	r ft.	R_u	Average R_u Values
1	R-sl	1.9	0.517	3.7	
3	R-sl	5.7	0.533	10.7	5.9
9	R-sl	1.7	0.505	3.4	
2	U-sl	2.2	0.375	5.9	
4	U-sl	1.0	0.412	2.4	
5	U-sl	1.3	0.655	2.0	2.9
6	U-sl	0.7	0.655	1.1	
7	D-fsl	1.4	0.502	2.8	
8	D-fsl	0.6	0.518	1.2	2.0

Referring to Table 3, it may be noted that the average
R_u value for the Richfield silt loam is 5.9. This particular
soil would be placed in the moderately rapid category. The
Ulysses silt loam and Dalhart fine sandy loam would be placed
in the moderate category.

In designing an irrigation system which had a 2600-foot
lateral located in a Richfield silt loam soil, it would be

necessary to know the expected water loss every 24 hours.

Using the values:

R_u = 5.9 cubic feet per square foot per 24 hours
r = 0.526 feet
p = 4.18 feet
L = 2600 feet
P = 3.1 cubic feet per square foot per 24 hours

Where $(Q_1 - Q_2)$ = PpL

$$= (3.1)(4.18)(2600)$$

$(Q_1 - Q_2)$ = 33,700 cubic feet per day or
0.77 acre-feet

From the above computation it may be shown that for every 2600 feet of ditch in Richfield silt loam, with the above dimensions, one could expect to lose 0.77 acre-feet of water for every 24 hours of operation.

MONETARY VALUE OF SEEPAGE

It was considered that these investigations would be more meaningful if an economic value could be placed on the water lost through seepage. A number of factors need to be considered. They are:

1. Number of acres irrigated.

2. Acre-feet of water pumped.

3. Cost of water per acre-foot.

4. Number of feet of ditches by soil type.

5. Total seasonal seepage loss.

The time that water is in a ditch is a factor that influences the total seepage loss on an individual farm. Under normal conditions an analysis of the time water is in ditches

on a farm shows that when irrigating, on the average, only half of the ditches will have water in them at any one time (1). For the purpose of calculating total losses throughout a season, the loss per thousand feet of ditch times the number of thousand feet of ditch on the farm divided by two will give the approximate total seepage loss for the season.

For the purpose of sample calculations, a hypothetical farm was used. The farm unit consisted of 320 acres, with a well having a capacity of 1300 gallons per minute and 140 feet of lift.

Hanson (2) reported average pumping plant costs in cents per acre-foot per foot of lift for natural gas pumping plants of 1000 hours of annual use was 4.53 and for 2000 hours of annual use it was 2.74. These values were used in this thesis.

Factors influencing average pumping plant costs are:

A. Capital investment in pumping plant:
    1. Cost of the well, screen and casing.
    2. Cost of pump.
    3. Cost of engine installed.

B. Annual pumping costs:
    1. Ownership costs:
        a. Interest on capital investment at 6 percent.
        b. Estimated taxes on pumping plant at 1 percent.
        c. Depreciation of engine or motor at 8 percent.
        d. Depreciation of pump and well at 5 percent.

    2. Operating costs:
        a. Fuel consumption costs.
        b. Lubricating oil and grease.
        c. Annual engine repairs.
        d. Annual pump repairs.
        e. Attendance, hours of labor.

Table 4. Estimated monetary value of seepage.

Item	Annual Hours of Use 1000	2000
A. Number of acres irrigated.	320	320
B. Acre-feet of water pumped.	241	482
C. Cost of water per acre-foot (2).	$6.34	$3.84
D. Number of feet of ditch by soil type.		
Richfield silt loam	5200	5200
Ulysses silt loam	1800	1800
E. Seasonal seepage loss.		
1. Percentage of water pumped.	16	16
2. Acre-feet.	38	76
3. Extra pumping cost.	$241	$292

Table 4 shows a breakdown of the monetary value of seepage for both 1000 hours and 2000 hours of annual use. The dollar values shown here are additional pumping costs only and no effort has been made to evaluate the cost of this water if it had been used for irrigating additional land. Assuming that this water was applied to the land and that it was used at maximum efficiency, then this water lost through seepage could be used to irrigate an additional 15 acres, based on an average use figure of 1.5 acre-feet per acre and 60 percent irrigation efficiency. The return from the additional 15 acres would depend on the crop and yield. Assuming a value of 46 dollars per acre as a net return per acre from irrigation, the 15 acres would return a total of 690 dollars. Deducting pumping costs from this value, the net balance would be 449 dollars for 1000 hours of operation and 398 dollars for 2000 hours of operation.

Only a 320-acre farm has been used for the purpose of placing a monetary value on seepage losses, however; this

could be carried even further and include the value of water lost to seepage throughout the entire state. Kansas has approximately 1,054,000 acres of irrigated land within the state. This would mean that there are approximately 4500 miles of water conveyance structures within the state, based on an average of 2 1/2 miles of irrigation ditch per 640 acres of land. Part of this figure would be buried pipe lines, lined ditches and gated pipe, but the major portion would be ditches in natural soil. Assuming a 4000 mile figure for the latter and only half of this having water at one time, an average seepage loss of 0.20 acre-foot per day per 1000 feet of ditch, it can be shown that the total water lost within the state per day is 2,112 acre-feet. Within an irrigating season there would be 105,600 acre-feet of water lost due to seepage. Based on an average use figure of 1.5 acre-feet per acre and 60 percent irrigation efficiency, there would be enough water to irrigate an additional 42,000 acres every season.

In other words, the Kansas irrigation farmers are paying 700,000 dollars a season for water that is never used for irrigation, but is lost through seepage in their irrigation ditches. The net income from the 42,000 acres would be approximately one million dollars. Thus it may be noted that they are not only paying for water that is never used, but also are losing considerable income.

SUMMARY

It is a common opinion that seepage and evaporation from irrigation ditches result in a loss of water of considerable proportion that could otherwise be used for irrigation. To substantiate this opinion, a number of seepage tests were made by measuring the difference between the inflow and outflow in irrigation ditches located in various areas of the principal soils found in Southwestern Kansas. Eight tests were conducted on seven different farms representing three soil series and two soil types.

While these tests were not extensive enough, both in number of tests and in soil conditions investigated, several important trends were established. Some of them are as follows:

1. Seepage from earth ditches results in loss of a large portion of water used for irrigation.

2. Evaporation losses amount to a very small portion of the total loss. The range for tests conducted was 0.5 percent to 3.5 percent. These values will of course vary from day to day in the same location.

3. Seepage from earth ditches in soils of Southwestern Kansas is approximately as follows: on Richfield silt loam, 7.5 percent for each thousand feet of ditch (for water entering a thousand-foot section of ditch) with a range of 4.6 to 10.5 percent and an average "loss factor" of 2.9 feet per day; on Ulysses silt loam, 2.8 percent per thousand feet of ditch with a range of 1.9 to 4.4 percent and an average "loss factor" of 1.2 feet per day; on Dalhart fine sandy loam, 1.5 percent, with a range of 1.0 to 2.0 percent, and an average "loss factor" of 1.0 feet per day. As water proceeds down the ditch, the percentage loss is reduced because the wetted area is constantly being reduced due to a change in water depth. Each 1000 feet of ditch must be considered independently in estimating losses.

SUGGESTIONS FOR FUTURE RESEARCH

Since the tests as reported in this investigation are in the nature of preliminary work and produce no conclusive evidence, additional seepage studies need to be made in order to determine more accurately the range of losses to be expected under various soil conditions. Other aspects would include the seasonal effect on seepage, and a thorough economic study. Research is recommended on long-term continuous-flow tests (season or year-around) on selected ditches in principal soil types. One question that arose during this investigation was, "how much water is lost through evapotranspiration along ditches that are weed infested?" It is the author's considered opinion that a ditch heavily infested with weeds and grass would lose more water in this manner than through evaporation.

Another aspect is; can there be a definite correlation between seepage losses and mechanical analysis of the ditch bed material. If enough data could be taken to substantiate this theory, it would be possible to predict, within reasonable limits, what water losses are occurring by taking a mechanical analysis of the bed material for a given soil.

With a growing concern for a critical water shortage in future years, it is evident that some means need to be developed for predicting probable water loss, with reasonable accuracy, in problem areas confronted by the irrigation designer and farmer.

ACKNOWLEDGMENT

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APPENDIX

LIST OF COOPERATORS

1. Fi-1   Garden City Experiment Station
                 Garden City, Kansas

2. Fi-2   G. T. Adams
                 Holcomb, Kansas

3. Fi-3 and 4   C. C. Spikes
                 Jerry Spikes (operator)
                 Garden City, Kansas

4. Gt-1 and 2   E. A. Dyck
                 W. H. Awtrey
                 Ulysses, Kansas

5. Sw-1   Hitch Land and Cattle Company
                 Clayton Green (operator
                 Liberal, Kansas

6. Sw-2   Hitch Land and Cattle Company
                 Bill Martin (operator)
                 Liberal, Kansas

7. Mo-1   Ralph Breeding
                 Richfield, Kansas

Table 5. Original data.

| Code No. | Date | Soil | Weather Data | | | | Evaporation Data | | | |
			Wind Vel. MPH	Barom. in. hg.	Air Tem.	RH %	Inch.	Elap. Time Hr.	Water Ditch	Temp. Pan
Gt-1	7-10-63	U-sl	0-10	30.01	98	40	.25	12	64	70
Gt-2	7-11-63	R-sl	0-10	29.96	98	60	.25	12	64	70
Fi-1	6-18-63	R-sl	0-5	30.02	79	42	.25	24	64	71
Fi-2	7-30-63	U-sl	12	29.93	95	45	.24	24	64	75
Fi-3	7-31-63	U-sl	16	29.95	104	15	.42	24	68	77
Fi-4	7-31-63	U-sl	16	29.95	104	15	.42	24	68	77
Sw-1	8-13-63	D-fsl	5	30.18	85	44	.20	17	66	72
Sw-2	8-14-63	D-fsl	5	30.05	83	44	.12	22	66	73
Mo-1	8-22-63	R-sl	12-25	30.00	98	25	.13	5.5	64	70

Table 5. (cont.).

| Code No. | Date | Soil | Ditch Data | | | | | | | |
			Leng. ft.	Dep. in.	Wid. ft.	WP ft.	Cross Section Area sq ft	In-flow gpm	Out-flow gpm	Slope ft/ft
Gt-1	7-10-63	U-sl	800	10.6	2.30	3.20	1.20	675	645	.0017
Gt-2	7-11-63	R-sl	800	12.0	3.00	3.85	2.05	871	779	.0010
Fi-1	6-18-63	R-sl	400	11.0	3.13	3.68	1.89	316	301	.0010
Fi-2	7-30-63	U-sl	1000	8.7	3.50	4.30	1.77	993	971	.0003
Fi-3	7-31-63	U-sl	800	15.7	5.50	6.70	4.39	1030	993	.0009
Fi-4	7-31-63	U-sl	800	15.7	5.50	6.70	4.39	993	973	.0006
Sw-1	8-13-63	D-fsl	600	9.4	5.54	6.24	3.13	1349	1321	.0010
Sw-2	8-14-63	D-fsl	500	12.0	4.85	5.96	3.09	1003	993	.0003
Mo-1	8-22-63	R-sl	1000	10.5	4.51	5.01	2.53	848	803	.0008

Symbols: Gt - Grant County   U   - Ulysses
          Fi - Finney County   R   - Richfield
          Sw - Seward County   D   - Dalhart
          Mo - Morton County   sl - Silt Loam
                                 fsl - Fine Sandy Loam
                                 MPH - Miles per Hour
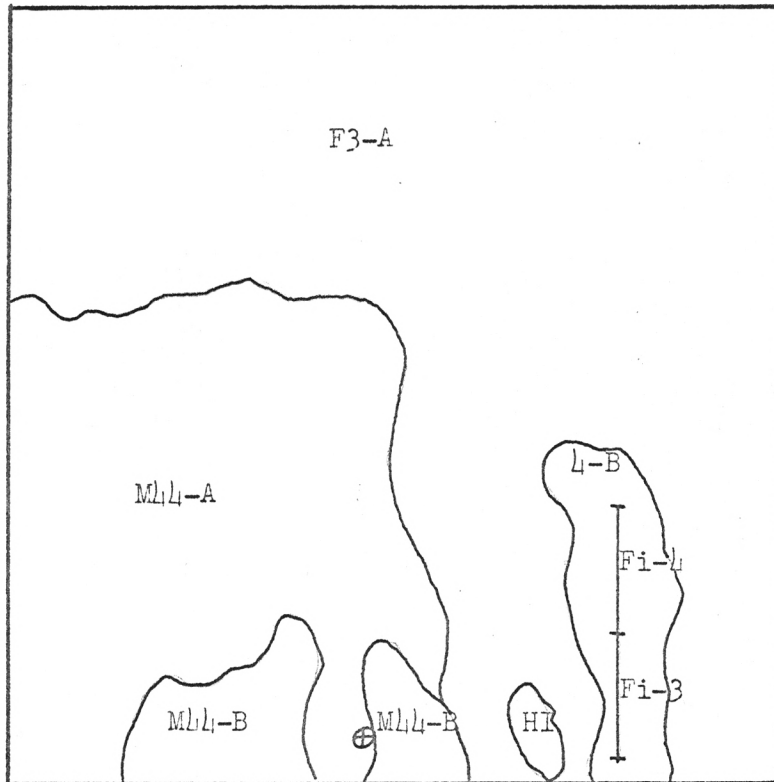   gpm - gallons per minute
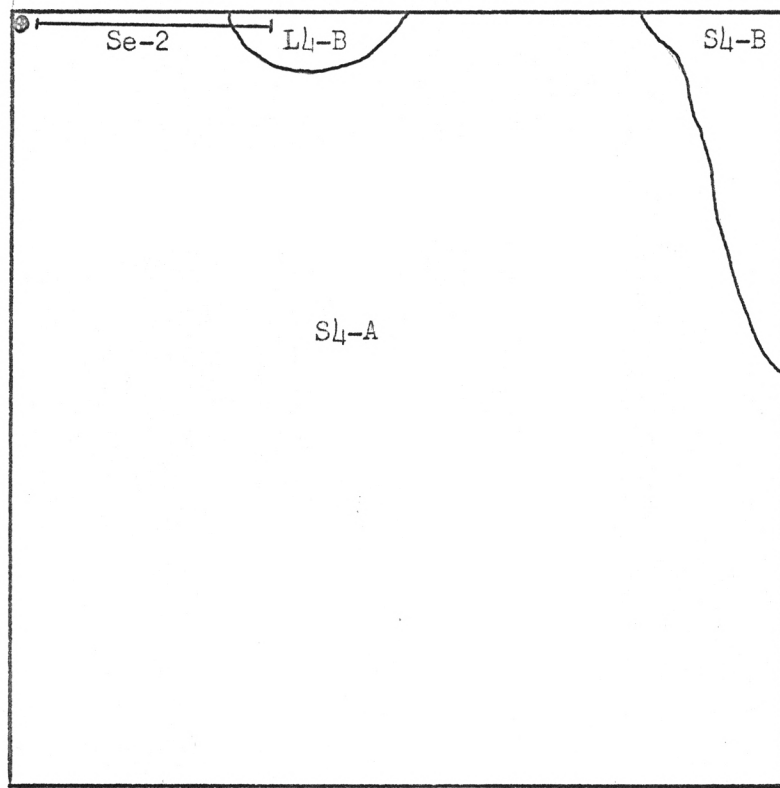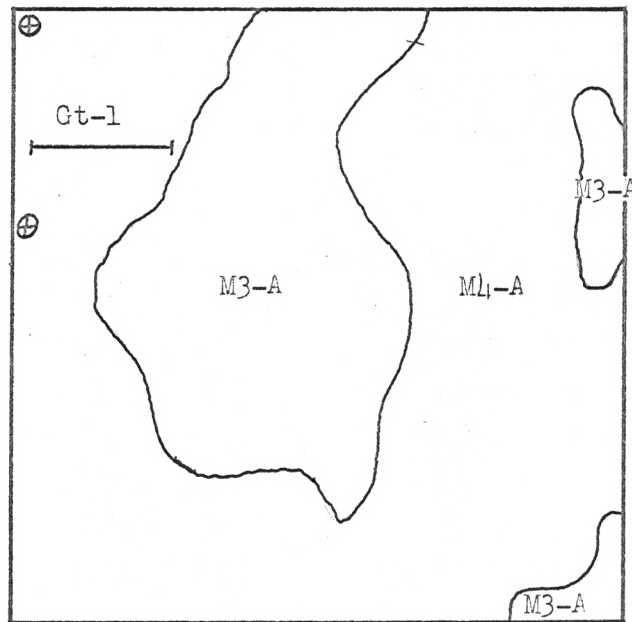
Section 32, T32S, R34W
Seward County
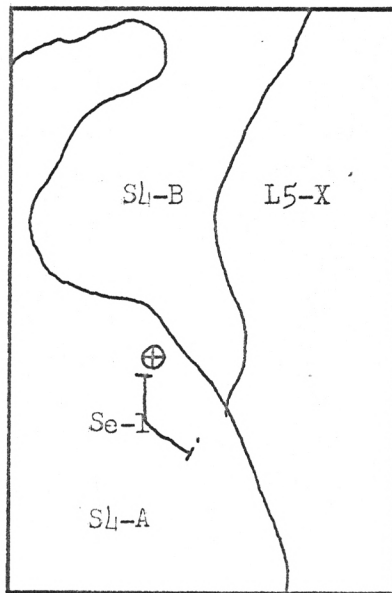
Section 27, T32S, R34W
Seward County

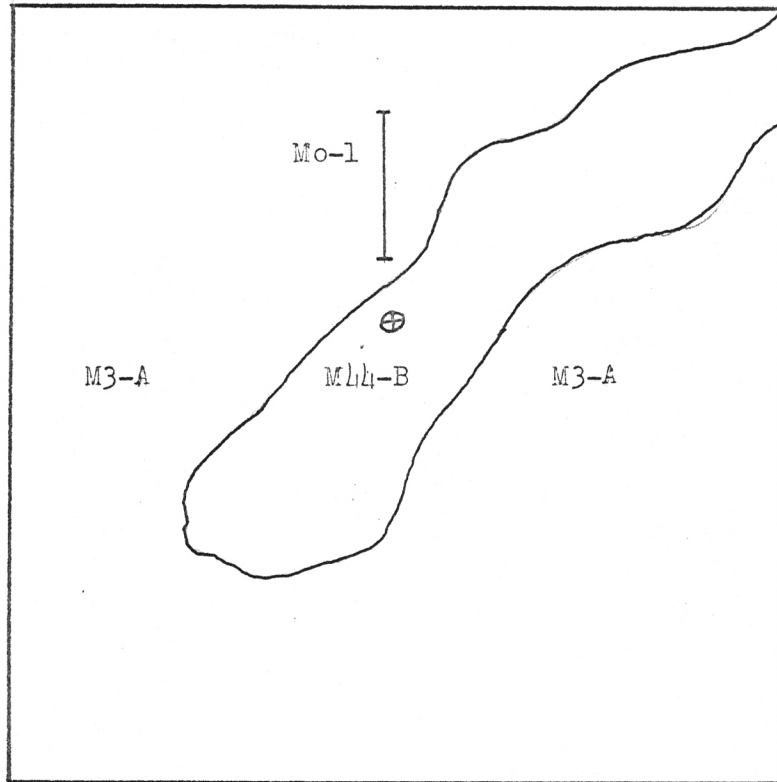Fig. 2. Map showing soil and location of test Se-1 and Se-2.
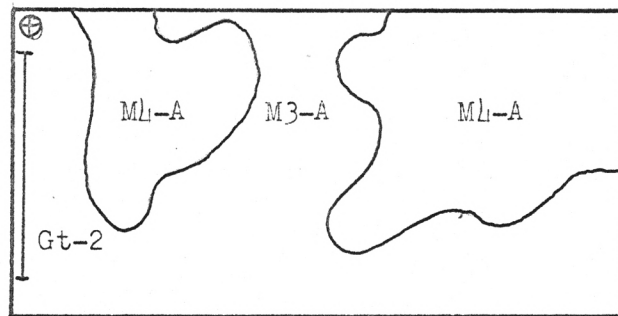
Section 31, T23S, R31W
Finney County

Section 8, T28S, R38W
Grant County

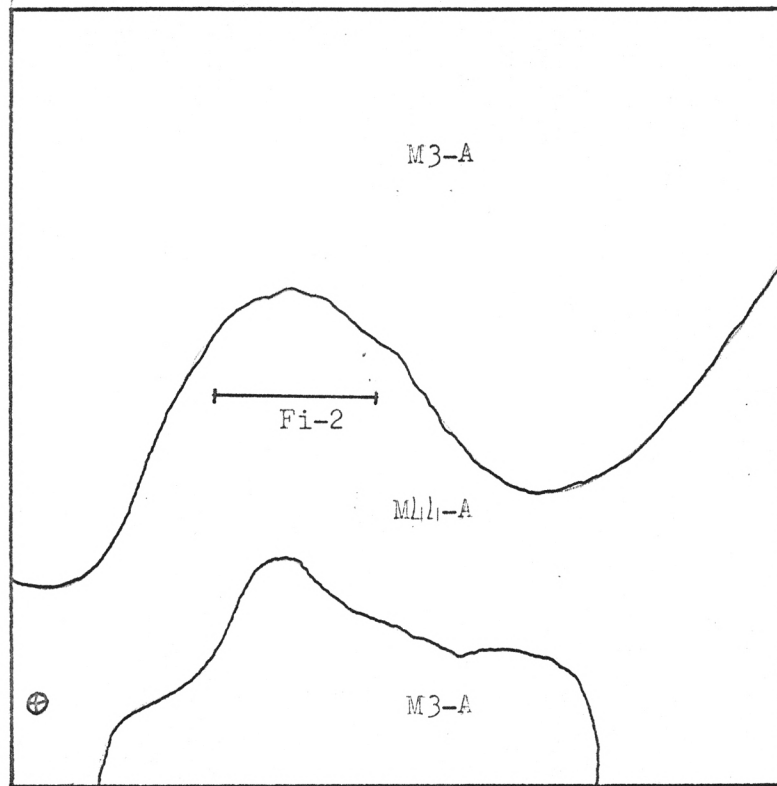Fig. 3. Map showing soil and location of test Fi-3, Fi-4 and Gt-1.

Section 27, T31S, R40W
Morton County

Section 18, T28S, R38W
Grant County

Fig. 4. Map showing soil and location of test Mo-1 and Gt-2.

Section 1, T23S, R34W
Finney County

Fig. 5. Map showing soil and location of test Fi-2.

Table 6. Orifice calibration data.

Head Ft.	Theoretical Flow c.f.s.	Measured Flow c.f.s.	Discharge Coefficient
		7-inch diameter	
.0167	0.277	0.160	0.58
.0417	0.438	0.275	0.62
.0708	0.571	0.350	0.61
.0875	0.634	0.375	0.59
.1000	0.678	0.402	0.59
.1417	0.807	0.484	0.59
.1917	0.939	0.570	0.60
.2250	1.018	0.615	0.60
			Average 0.5975
		12-inch diameter	
.0083	0.574	0.350	0.61
.0250	0.996	0.590	0.59
.0167	0.814	0.490	0.60
.0333	1.150	0.690	0.60
			Average 0.600
		16-inch diameter	
.0083	1.025	0.610	0.60
.0167	1.454	0.870	0.60
			Average 0.60

PERMEABILITY CHARACTERISTICS OF WATER CONVEYING DITCHES
LOCATED IN IRRIGATED SOILS

by

JERRY D. DICKERSON

B. S., Kansas State University
of Agriculture and Applied Science, 1957

AN ABSTRACT OF
A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agricultural Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1964

In 1962, Kansas had more than one million acres of irrigated farm land. Some thirty-eight thousand acres are served from reservoirs and the balance is served by pumping plants drawing water from wells and streams. In either case, every irrigated farm has some type of distribution system to deliver the water from the source to the land. It has been estimated that there are over 4000 miles of open ditches involved in the process of delivering this irrigation water to the fields.

With a growing concern for a critical water shortage in future years, there is an ever-increasing need for conservation of water in areas where water is needed for irrigation. Various programs and developments have been initiated by private companies and Federal agencies to find ways of eliminating excessive conveyance losses in irrigation canals and ditches. As an initial part of any program, it is important to know the amount of the losses and where the losses are occurring. Seepage losses usually represent the major portion of canal conveyance losses.

In view of the above facts, a seepage loss measuring program was organized to measure the seepage losses in irrigation ditches on individual farms. Of primary interest were the soils in which the major portion of the irrigated acreage was located. As a result, three soils were chosen to conduct a seepage loss investigation. These soils were:

1. Richfield Silt Loam

2. Ulysses Silt Loam

3. Dalhart Fine Sandy Loam

After sites had been selected to conduct the investigation, a method for determining the seepage losses was selected. It was decided that the inflow-outflow method was the most logical one to use. A length of ditch section, or "reach", was selected for conducting the study. The water measuring devices were set in the ditch at the inlet and outlet ends of the test section. A record of hourly flow past each station was taken and the difference between the inflow and outflow determined the seepage losses plus evaporation losses. Evaporation losses were measured and deducted from the gross loss. The latter figure was then the net seepage loss through the soil in the ditch section.

While these tests were not extensive enough, both in number of tests and in soil conditions investigated, several important trends were established. It was found that seepage from earth ditches results in the loss of a large portion of water used for irrigation. Evaporation losses amount to a very small portion of the total loss. The results of the study show that evaporation losses ranged from 0.5 to 3.5 percent while seepage losses ranged from 1.0 to 10.5 percent. The range of losses for a Richfield silt loam was 4.6 to 10.5 percent, Ulysses silt loam 1.9 to 4.4 percent, and Dalhart fine sandy loam 1.0 to 2.0 percent.

Based on 4000 miles of earth ditches and an average seepage loss of 0.20 acre-feet per day per 1000 feet of ditch, it can be shown that the total water lost due to seepage in

the state, within an irrigation season, could be as much as 105,600 acre-feet. If this water were retained and applied to the land, it would irrigate an additional 42,000 acres of land every season. This was based on an average use figure of 1.5 acre-feet per acre and 60 percent irrigation efficiency.

The additional pumping costs for this water would amount to approximately 700,000 dollars every season and the net income from this additional acreage would be approximately one million dollars, based on current prices for an average irrigated crop.