Progress Report

STUDY OF SEEPAGE LOSSES FROM IRRIGATION CHANNELS 1952

By

A. R. Robinson

and

Carl Rohwer

April 25, 1953

CER54ARR13

U. S. DEPARTMENT OF AGRICULTURE

SOIL CONSERVATION SERVICE

Progress Report
on the

STUDY OF SEEPAGE LOSSES FROM IRRIGATION CHANNELS

1952

by

A. R. Robinson, Assistant Irrigation Engineer
Carl Rohwer, Senior Irrigation Engineer
Division of Irrigation Engineering
Soil Conservation Service

A contribution from the
Division of Irrigation Engineering and Water Conservation
in cooperation with the
Colorado Agricultural Experiment Station
and the
U. S. Bureau of Reclamation

Fort Collins, Colorado
April 23, 1953

Prepared under the direction of George D. Clyde, Chief
Division of Irrigation Engineering and Water Conservation
Soil Conservation Service

CONTENTS

PROGRESS REPORT
STUDY OF SEEPAGE FROM IRRIGATION CHANNELS
1952
by
A. R. Robinson and Carl Rohwer

INTRODUCTION

One phase of the Lower Cost Canal Lining Program of the Bureau of Reclamation is the study of methods of making seepage loss measurements. In furtherance of this program, the Bureau, early in 1949, requested the Division of Irrigation Engineering, Soil Conservation Service and the Colorado Agricultural Experiment Station to cooperate with them in making seepage studies. After several conferences a plan for conducting the study was agreed upon and a Memorandum of Understanding ASc-875, effective June 30, 1949, was signed by the cooperating agencies. The Memorandum of Understanding has been renewed annually. Work on the project was started in the summer of 1949 and has been carried on continuously since that time.

The purpose of this investigation is to study the factors that cause seepage and to determine their effect on the rates of seepage in order that better methods of measuring seepage from existing canals and of forecasting the seepage from proposed canals might be devised. One phase of the study is based on the construction of seepage rings in different types of soil, from which the seepage could be accurately determined and in which a study of the various factors influencing seepage could be made. The seepage rates from these rings would also be used as a standard for determining the accuracy of seepage measurements by different types of seepage meters installed within the rings. Actual field use of the seepage meters as well as well-type permeameters on existing or proposed canals as a means of further improving or calibrating the equipment was planned. Complete water and soil analyses including laboratory permeameter measurements would be made.

During the first three years of operation the seepage rings were installed in clay loam, sandy loam and clay. Frequent measurements were made with the seepage meters at each location. Observations of ground water elevation, rainfall, water and air temperature and evaporation were also made at each location. Well permeameter tests were made along the completed Poudre Supply Canal and assistance was given in well-permeameter tests along the proposed North Poudre Supply Canal. Inflow-outflow measurements were made on the Arthur Ditch and ponding and seepage meter tests were made on a section of the Poudre Supply Canal. Complete analyses were made of the soil at each test location.

During 1952, the seepage rings were installed in sand at the Bellvue Laboratory and sandy loam at the Poudre Supply Plot. In addition to the observations made as in past years, soil thermometers to record the temperature at one-inch and one-foot depths, were installed inside the rings. Frequent observations using the seepage meters, were made at each location. Special equipment was constructed at the Bellvue Laboratory for the purpose of studying the effect of distance to ground water on the seepage rate, and a short canal section was excavated at the Poudre Supply Canal seepage plot for comparing the results of seepage measurements by different methods. Well permeameter tests were made before the section was excavated and ponding and seepage meter tests were made after the section was filled with water. Well permeameter tests were also made outside an excavated section of the Poudre Supply Canal and ponding tests were made in the section after the irrigation season.

ACKNOWLEDGMENTS

The authors of this report wish to acknowledge the assistance of Messrs. Floyd Roush, Dale Lancaster and Chester W. Jones of the Bureau of Reclamation and Dr. Dean F. Peterson of the Colorado Agricultural Experiment Station in conducting the study and interpreting the results. Mr. Andrew Williamson assisted in the field work for the project. Laboratory tests of the physical and chemical properties of the soil were made by Mr. Robert C. Accola, Soil Scientist, Soil Conservation Service, and David W. Fonken, senior Civil Engineering student at Colorado A and M College. Mr. Barrie Binford, senior Forestry student, Colorado A and M College, made the drawings for the report. The report was typed by Mrs. Lois B. Klemmedson.

The Jackson Ditch Company provided the site for the Bellvue Laboratory seepage study and the site for the Poudre Supply seepage plot was furnished by the U. S. Bureau of Reclamation.

EQUIPMENT AND PROCEDURE

Seepage Rings

As explained in previous progress reports (7), (8), (9), the seepage rings consisted of two concentric rings, one 6 feet and the other 18 feet in diameter. The rings were three feet deep and were set into the soil one foot thereby forming tanks which were two feet deep. (See figure 1.) The water for the Bellvue rings was obtained by pumping directly from the Poudre River into a storage tank from which the water for the ring was drawn after the sediment had settled out. At the Poudre Supply plot the water was taken from the Fort Collins city water line. Water entering the rings was measured through calibrated, domestic-type water meters. Float valves in each ring controlled the flow with the inner rings also being controlled with magnetic valves. These valves allowed high rates of flow for short periods so that a more accurate measurement of discharge could be made. Hook gages mounted in each ring were used to measure any fluctuation in the water surface. For measuring the ground water levels, piezometers were installed at locations outside the outer ring as well as at different depths inside the inner ring. Soil thermometers were placed in the inner ring, one giving the temperature at one inch and the other at one foot below the ground surface.

Twice-daily observations were made at the seepage rings. These observations consisted of recording the flow through the

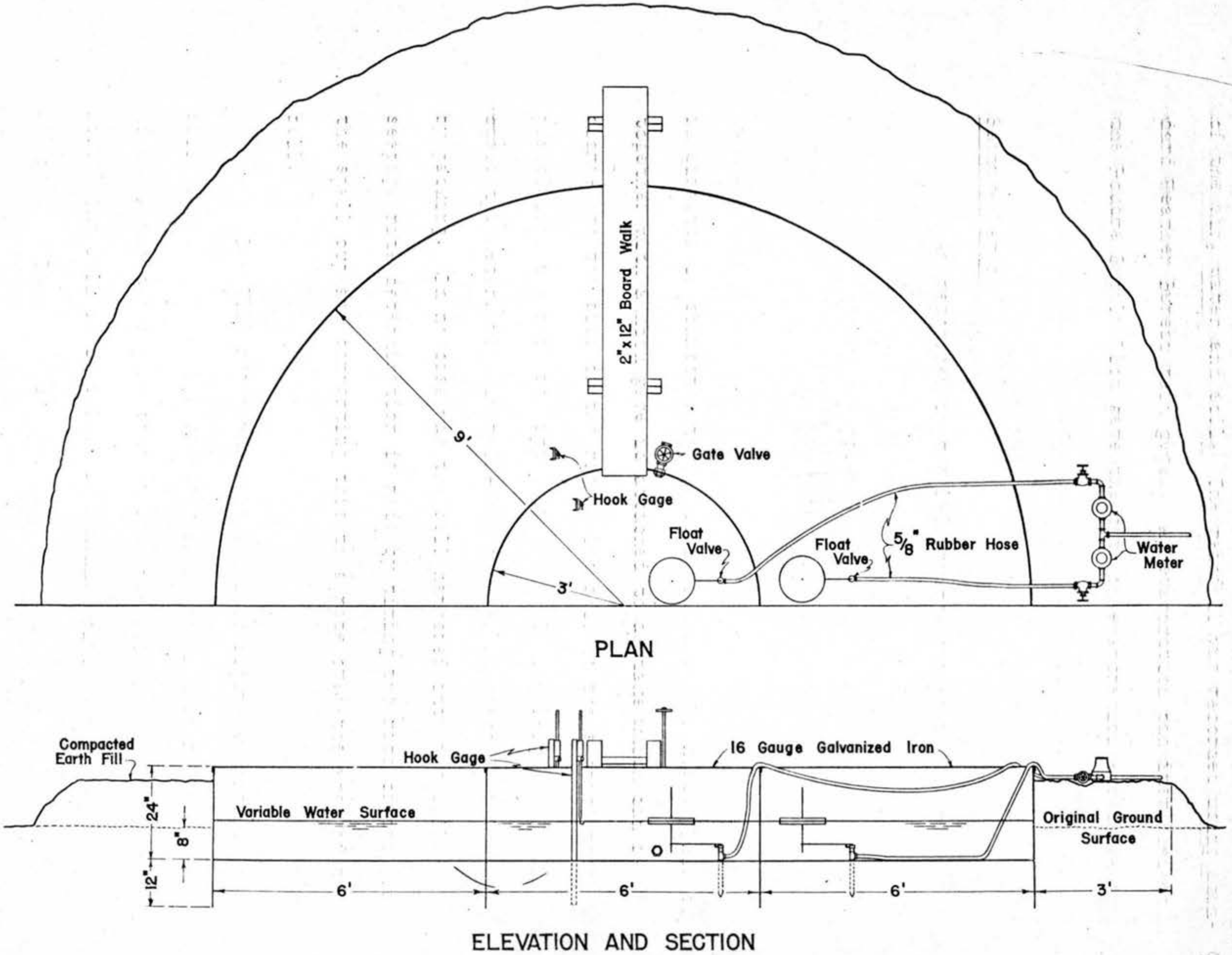


FIGURE 1.- SEEPAGE RINGS

meters, the fluctuation of the water surface and the temperature of the air, water and soil. The rainfall was recorded using standard Weather Bureau rain gages. An evaporation pan installed at the Poudre Supply Plot gave the data on evaporation and these data were also used for the correction for the Bellvue plot.

Seepage Meters

As described in the 1951 progress report (8), two types of seepage meters were used in the study. One type has been termed the SCS meter and the other the USBR meter. The SCS meter, which is shown in figures 2 and 3, consists of a metal bell, one foot in diameter and 6 inches deep. A cup approximately 2 inches in diameter is connected to the bell with a rubber hose. This cup together with a hook gage is attached to a stake which can be clamped to the side of the ring. The bell of the seepage meter is pushed into the soil for approximately half its length. In all cases the meters were installed by two men standing on the bell or by jacking. In no case was the bell hammered into the soil. A seepage rate determination is made by timing the rate of drop in the small cup and converting this to a rate over the area of the bell.

The USBR meter which is shown in figure 4 consists of a bell, 2 square feet in cross-sectional area and from 8 to 12 inches high. A plastic bag is connected to the bell by a flexible plastic hose. The bell is installed in a manner similar to that for the SCS meter. To make a determination with this meter the plastic

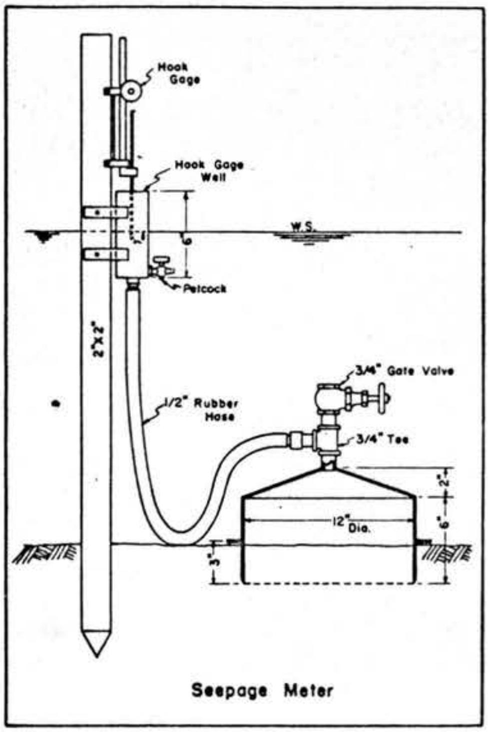


Figure 2.-- SCS seepage meter.

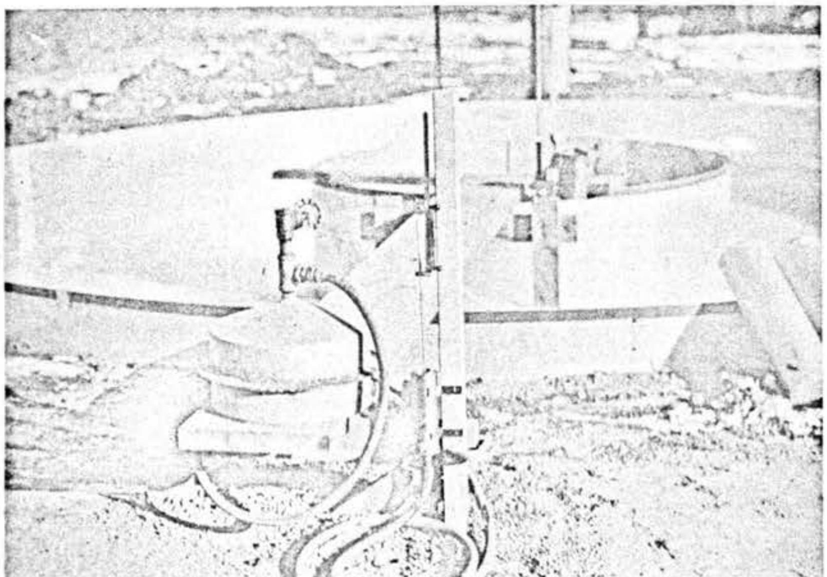


Figure 3.-- SCS seepage meter with metal bell.

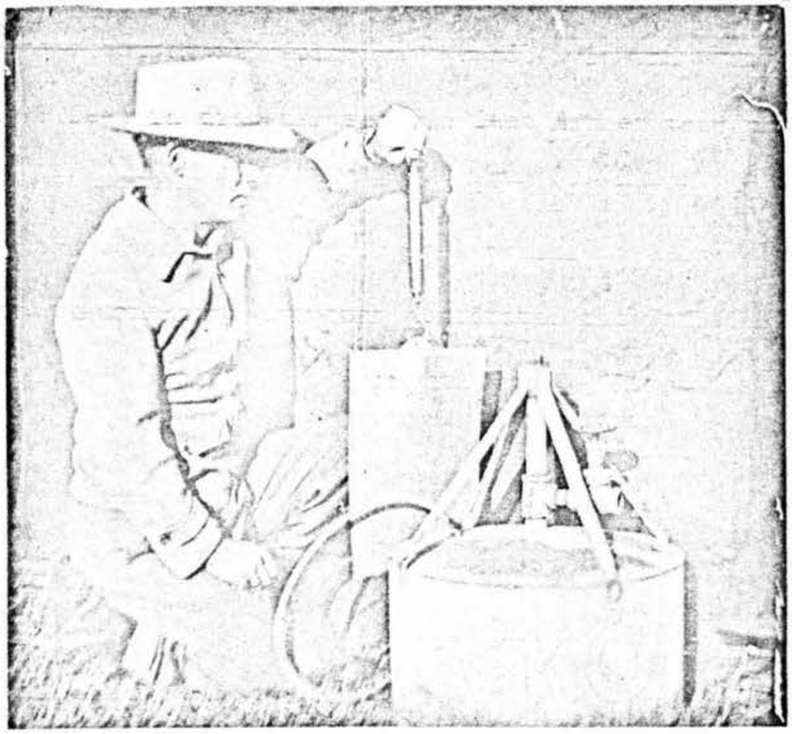


Figure 4.-- USBR seepage meter with plastic bag.

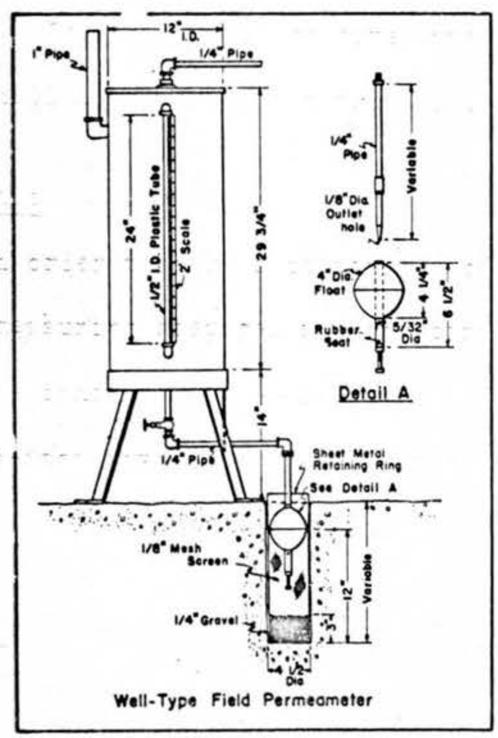


Figure 5.-- Well type permeameter.

bag is filled with water, weighed and attached to the meter with the flexible hose. The valve on the top of the bell is closed and the clamp on the flexible hose opened. After a prescribed length of time the bag is removed and again weighed. This gives a seepage rate per unit of time over the area of the bell.

Well-type Permeameter

The well-type permeameter was developed by the U. S. Bureau of Reclamation and is fully described in their Earth Manual (12). This permeameter which is shown in figure 5, consists of a calibrated supply tank equipped with an indicator glass and an outlet pipe equipped with float mechanism. An uncased hole 4 to 6 inches in diameter and varying in depth with the horizon to be tested is used. The hole is partly filled with highly permeable sand or gravel to reduce erosion and prevent caving with the upper portion equipped with a screen casing. A constant water level is maintained in the hole by the float mechanism. The discharge to maintain this constant water level is determined by noting the drop in the calibrated tank. The tests are continued for a period of approximately one week with readings made at frequent intervals during the day. In addition to tank readings, the temperature and depth of water in the hole are noted.

Seepage Ring for Ground-Water Elevation Study

In order to study the effect of the depth to ground water on the seepage rate, special equipment as shown in figure 6 was constructed. This consisted of a ring 12 feet in diameter with a concrete bottom and filled with soil. In this ring was placed a ring 6 feet in diameter set two feet higher than the 12-foot ring, so as to accommodate a two-foot depth of water. The larger ring had a 3-inch thickness of gravel immediately above the concrete floor. A one-inch diameter perforated pipe embedded in this gravel, served as a drain for the ground water. Removable sections, six inches long and attached vertically on the end of this pipe were used to adjust the depth of ground water. Three piezometers equally sqaced around the outer ring were used to measure the distance to the ground water. The inner ring contained a hook gage and two soil thermometers.

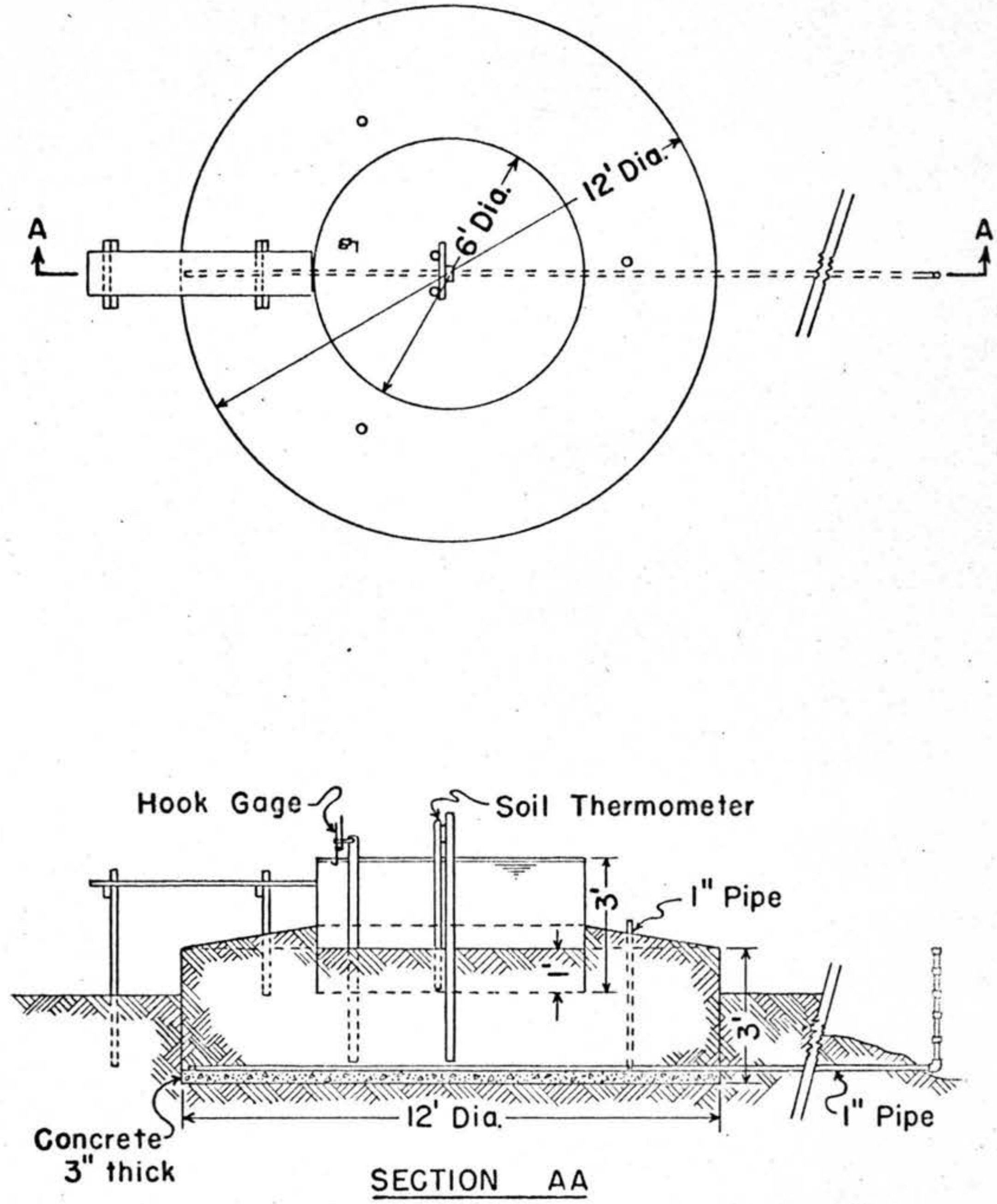
The readings taken on the ring were similar to those for the seepage rings with the addition of ground water elevations taken daily. The inflow was measured with a domestic water meter and was controlled with a float valve and also a magnetic valve.

Canal X-Section

In order to make a comparison of the results of different methods of measuring seepage, a short canal section as shown in figure 7, was constructed. This canal was 18 feet long and 3 feet deep, with 3-foot bottom and 1-1/2:1 side slopes. Water-tight bulkheads were placed at each end to check the elevation of the water surface.

Before excavation, well permeameter tests were made along the center line of the section. After excavation, the

Figure 6



Seepage Ring for Study of Effect of Ground-Water Fluctuation

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, RESEARCH

section was filled with water and, when conditions became stabilized, ponding tests were made over a period of several weeks. During the ponding tests, seepage meter tests also were made along the bottom.

Figure 7.-- Canal Section, Poudre Supply Plot

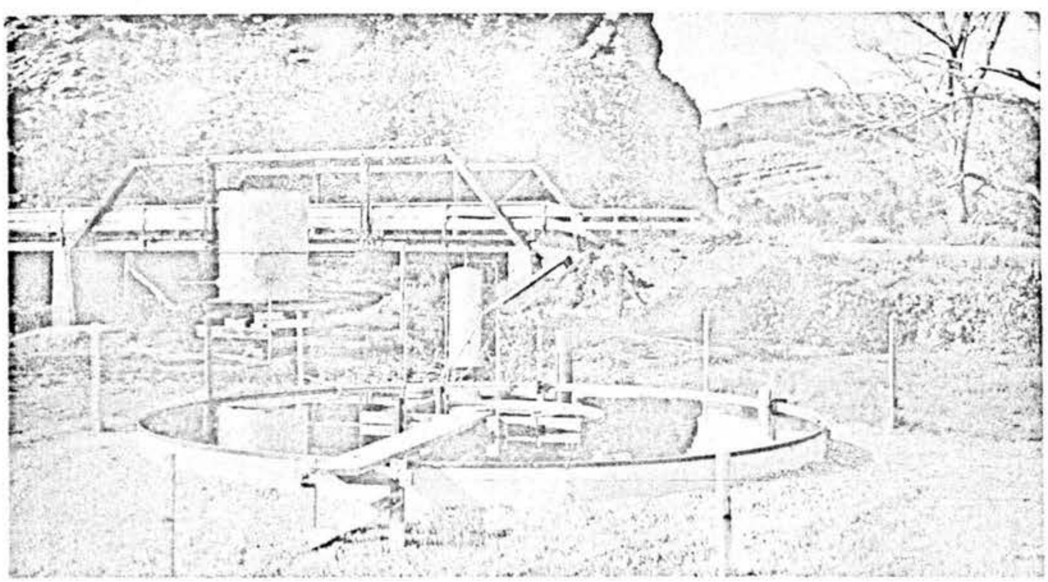


Figure 8.-- Seepage rings at Bellvue Plot with well type permeameter and settling tank in background.

PRESENTATION OF DATA

Bellvue Laboratory Seepage Tests

Seepage Rings

Since seepage tests had been made in the existing material at the Bellvue Laboratory Plot for two previous seasons it was desired to make tests on a new, more permeable material. A relatively coarse, screened sand was chosen for these tests. To make the tests the old material was excavated and replaced with new material. The excavation was made to a depth of approximately three feet over an area 20 feet in diameter. The underlying material, which consisted of coarse sand and a few large cobbles, was highly permeable. After the hole had been excavated to the desired depth it was refilled with the coarse sand and the rings replaced. The sand was carefully shoveled into the rings in layers and then compacted by turning water into the rings. A picture is shown in figure 8.

The mechanical analyses of the soils, which were made using the procedure set forth by the American Society of Testing Materials, are plotted in figure 9 and tabulated in table 1. According to the U. S. Bureau of Soils specification the samples of the new material were classified as sand. The underlying material consisted of approximately 40 percent sand with the remaining 60 percent greater than 2.0 mm. in size. The chemical analysis of the soils showed them to be alkaline in reaction.

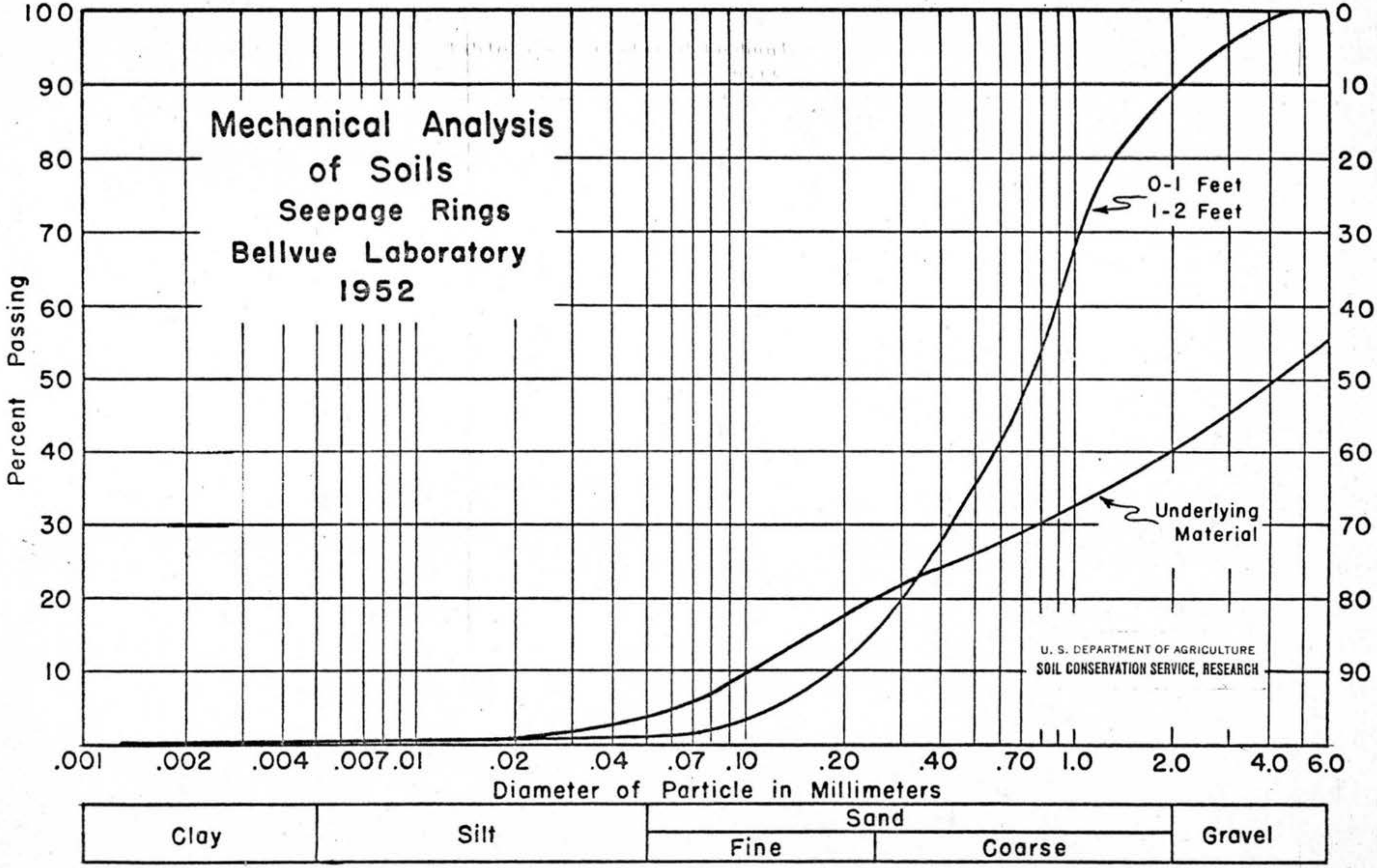

Mechanical Analysis
of Soils
Seepage Rings
Bellvue Laboratory
1952
0-1 Feet
1-2 Feet
Underlying
Material
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, RESEARCH
Percent Passing
Percent Retained
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
80
90
.001
.002
.004
.007
.01
.02
.04
.07
.10
.20
.40
.70
1.0
2.0
4.0
6.0
Diameter of Particle in Millimeters
Clay
Silt
Sand
Fine
Coarse
Gravel

Figure 9

Table 1.-- Combined Mechanical Analysis of Soils
Seepage Rings, Bellvue Laboratory
1952

Sample Location	Colloids .001 mm	Clay .001-.005 mm	Silt .005-.05 mm	Fine Sand .05-.25 mm	Coarse Sand .25-2.0 mm	Gravel 2.0 mm	U. S. Bureau of Soils Classification
	Percent	Percent	Percent	Percent	Percent	Percent	
0-1 Ft.	0.0	0.5	0.5	14.0	74.0	11.0	Sand
1-2 Ft.	0.0	0.5	0.5	14.0	74.0	11.0	Sand
Underlying Material	0.0	0.5	3.5	16.0	21.0	59.0	Sand and Gravel

Table 2.-- Chemical Analysis of Soils
Seepage Rings, Bellvue Laboratory
1952

Sample Location	pH 1:5	Total Soluble Salts	Total Gravimetric Salts	Organic Material	Ca CO_3 (Lime)	Disturbed Permeability K
		Percent	Percent	Percent	Percent	Ft/day
0-1 Ft.	7.9	.02	0.5	0.1	0.1	0.8
1-2 Ft.	7.9	.02	0.5	0.1	0.2	3.8
Underlying Material	8.1	.02	0.5	0.8	0.6	2.4

(See table 2.) The soluble salt content was very low and no gypsum was indicated. The lime content was also very low. The water, which was obtained from the Poudre River, shows a very low salt content. (See table 3.) Atterburg Classification tests were not made on the samples because of the friability of the soil.

Permeability tests of disturbed soil samples were made in the laboratory according to the procedure described in the 1950 progress report on soils (10). Approximately 350 gms. per sample were dried and passed through a 2 mm. sieve. The sample was poured into a 2.2 inch (ID) lucite percolation cylinder from a height of 21 inches above the base using a funnel and rubber hose. For compaction the cylinder was dropped ten times on a block of soft wood from a distance of 2.5 cm. In order to eliminate as much trapped air as possible, water was initially allowed to percolate up from the bottom of the sample. The actual tests, however, were made with the water percolating downward.

Percolation rates were obtained on the samples for periods of approximately 16 days. Shown in figure 10 are the average computed permeabilities for the duplicate samples plotted against time. These determinations show that the end permeabilities were approximately 0.8 foot per day for the 0-1 foot sample of the sand and 3.8 for the sample for 1-2 feet. For the underlying material this permeability was about 2.4 feet per day. Although the sample of the underlying material contained some larger gravel only the material which passed a 2 mm. screen was used for the permeability test.

Table 3.-- Water Analysis

	Ft. Collins City Water	Poudre River Water*
Total Solids	66 PPM	92 PPM
Volatile Matter (Organic & H_2O)	14 PPM	22 PPM
Organic Matter	Trace	Trace
Reaction (acid-alkaline)	6.9 pH	7.0 pH
Bases		
CaO - Lime	Slight	Light
MgO - Magnesia	Slight	Slight
Na_2O - Soda	Present	Present
Acids		
NO_3 - Nitrates (toxic)	None	None
CI - Chlorides (table salt)	None	None
SO_3 - Sulfates	Trace	Slight
CO_2 - Bicarbonates	Trace	Trace

* Samples at Bellvue Laboratory. Water contains about 20 PPM of clay sediments.

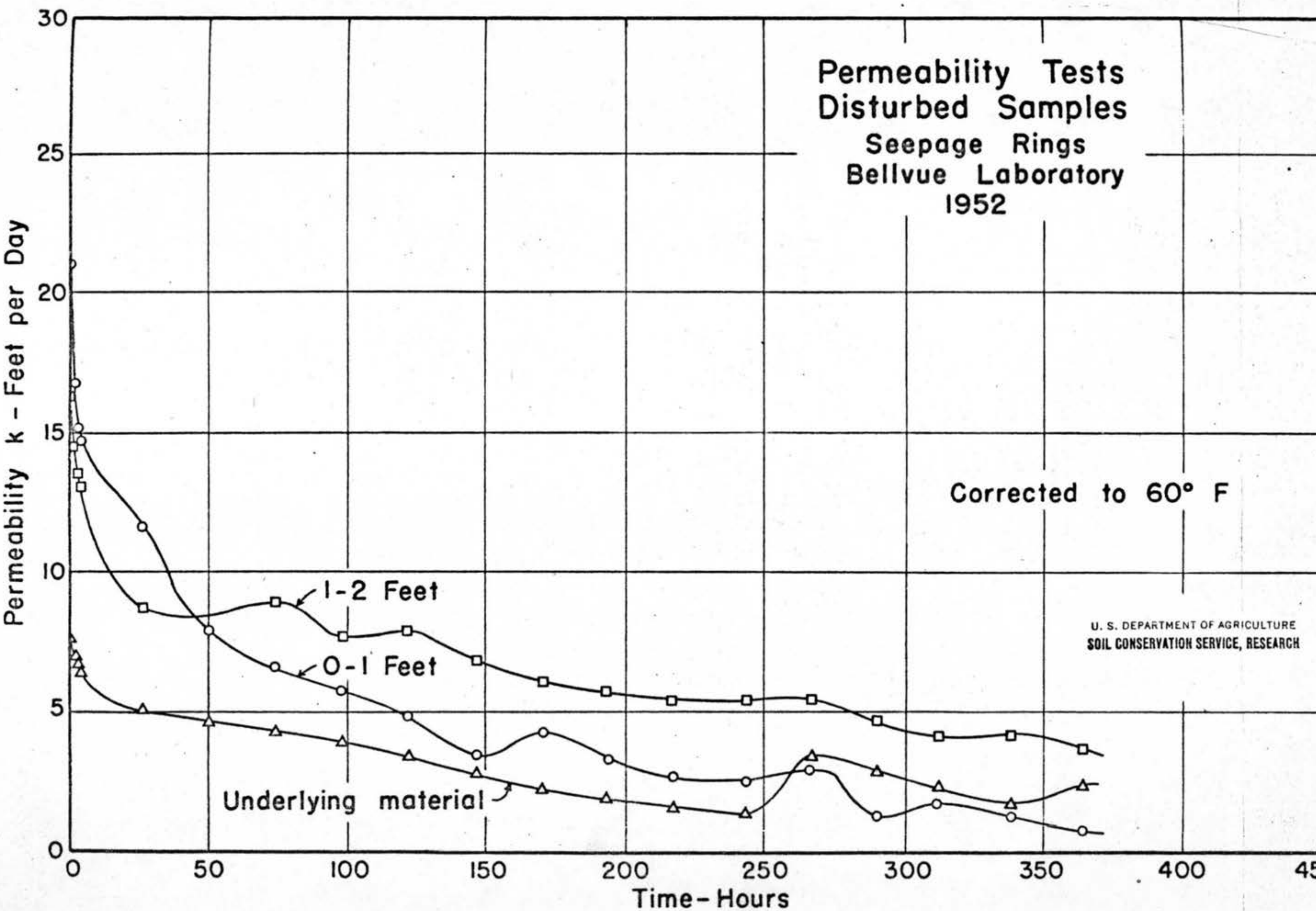

Permeability Tests
Disturbed Samples
Seepage Rings
Bellvue Laboratory
1952
Corrected to 60° F
1-2 Feet
0-1 Feet
Underlying material
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, RESEARCH
Permeability k - Feet per Day
Time - Hours
0
5
10
15
20
25
30
0
50
100
150
200
250
300
350
400
450

Figure 10

Water was first turned into the seepage rings on June 18 and thereafter continuous tests were made until October 23 when the water was turned off for the winter. The initial seepage rates were so high that some difficulty was encountered in supplying enough water. On several occasions, because of a rise on the river, silt was brought in with the water. For this reason the bottom of the rings was raked at two different times to break up the silt layer. Near the middle of the testing period the inner rate became so low that it was necessary to install a magnetic valve to control the flow. With this valve, the flow was restricted to short periods at a high rate, which facilitated accurate measurement. The water was cut off frequently and the rate of drop noted over a one or two hour period. This gave a positive check of the seepage rates as determined from the measured inflow. This test has been termed a "drop test" in this report.

A plot of the observed seepage rates as well as the data on water depths, water and soil temperature, and barometric pressure is shown in figure 11. The seepage rates have been corrected for precipitation and evaporation. Because of the volume of water needed to keep the rings filled it was necessary to operate with the rings interconnected for the first month. The initial seepage rate through the sand was approximately 7.0 feet per day. This rate increased for about 20 days until a maximum rate of 15.0 feet per day was reached after which the rate decreased to the original 7.0 feet per day. Since silt had entered the rings during the

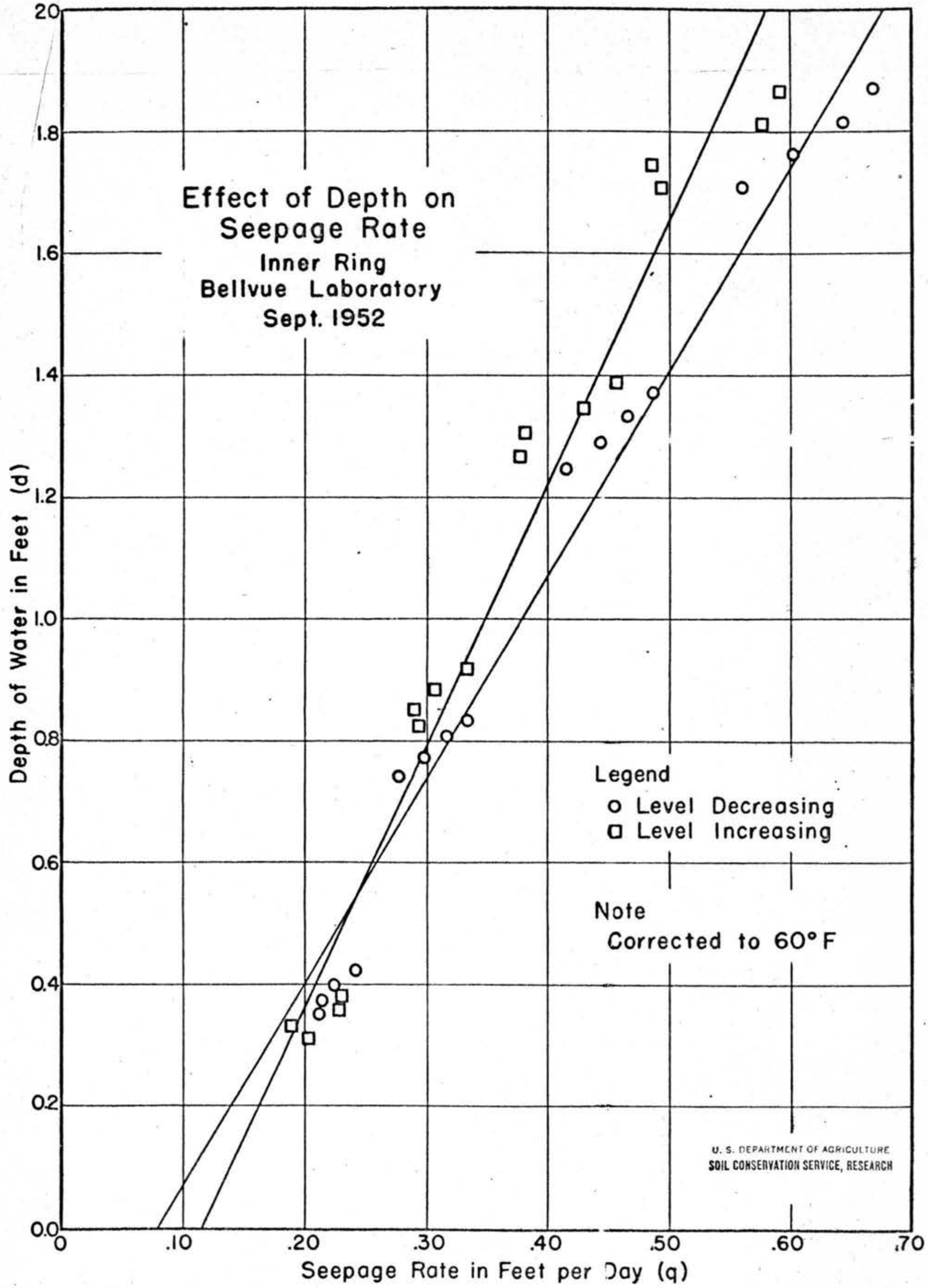

Barometric Pressure
Inches - Mercury
25.4
25.2
25.0
24.8
Water Temperature - Bottom and Soil Temperature at One Foot
Temperature °F
80
70
60
50
40
Seepage - Feet per Day
15.0
10.0
5.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Switch failed - Rings dry
Tamped surface of rings - found large hole in inner ring
Hose siphoned
Seepage Rate Rings Interconnected
Bottom raked
Meters calibrated
Seepage Rate Outer Ring
Hose disconnected
Effect of Temperature Test
Seepage Rate Inner Ring
Effect of Depth Test
Bottom raked
Inner Ring ran over
Water Depth
Water Depth Feet
2.0
1.5
1.0
0.5
Legend
Drop Test - Outer Ring
Drop Test - Inner Ring
S.C.S. Seepage Meter
U.S.B.R. Seepage Meter
June
July
August
September
October
Seepage Rings
Bellvue Laboratory Plot
1952
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, RESEARCH

time that the water from the river was turbid because of flood flows it was necessary to rake the surface on two occasions to break up the silt layer. After raking the rates were temporarily increased.

After the interconnecting valve between the rings was closed and the two rings operated separately, the seepage rate from the outer ring was always higher than from the inner ring. The results of the drop tests are always very near the rate determined for the continuous record. The rates from both rings dropped below 1.0 foot per day on the 1st of September. After raking the bottom of the rings, these rates increased to 3.5 feet per day, but from then on there was a general decline until the end of the period. At this time the inner ring had a rate of 0.4 foot per day as compared to 0.8 for the outer ring. During all of the period the water temperature at the bottom and the soil temperature at 1.0 foot were practically the same.

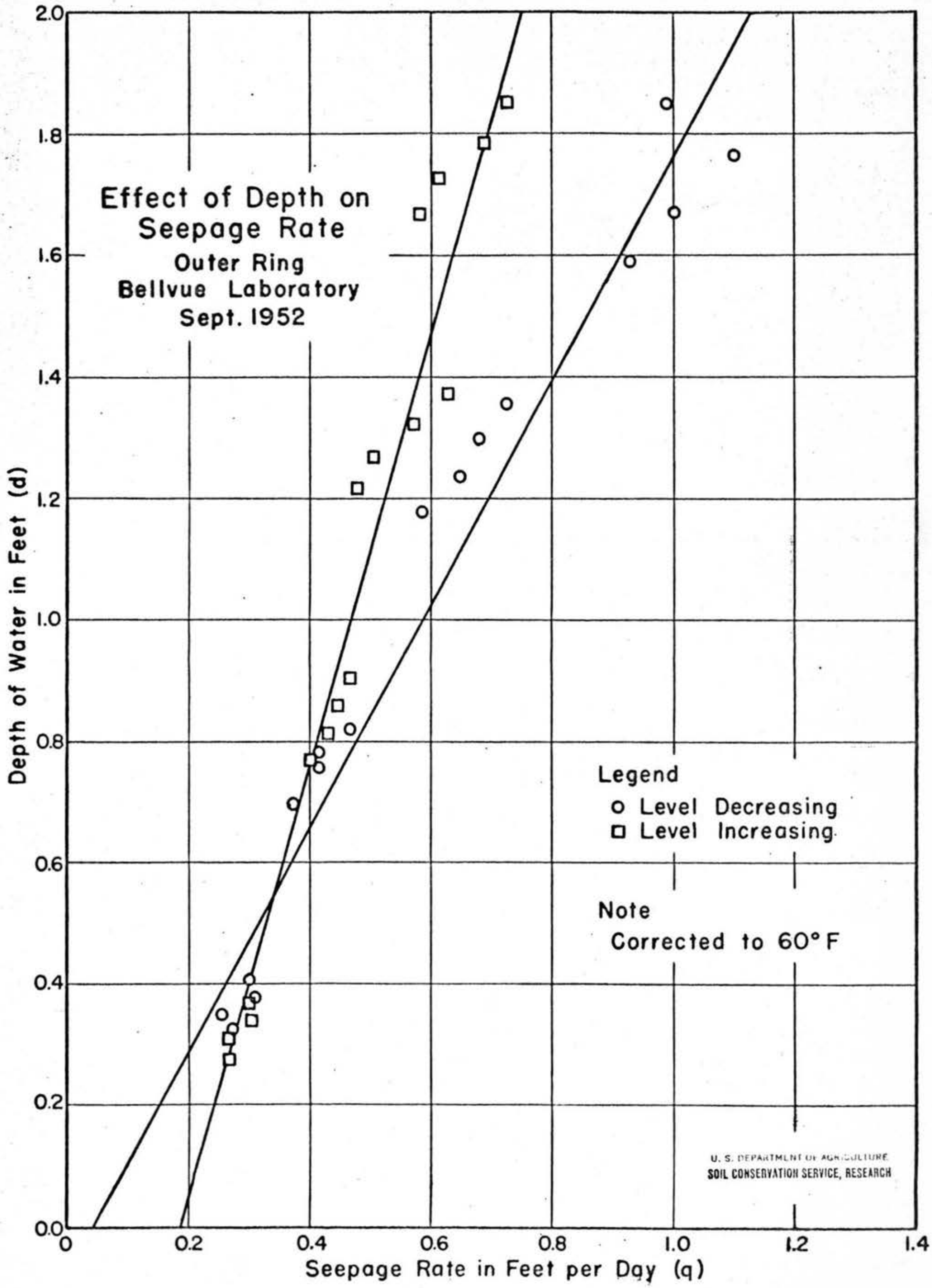
During the period from September 2 to 10, tests were made to determine the effect of depth of water on the seepage rates. Plots of the results of these tests are shown in figures 12 and 13. For these tests, with the inflow shut off, the water was allowed to drop during the day, and during this time the drop for two-hour periods was noted. At the end of the day the floats were set down approximately 6 inches thereby lowering the water levels an equivalent amount by the next morning. This procedure was repeated until near zero depth was reached. The water was then brought up by successive steps until maximum depth was again maintained.

Figure 12



Effect of Depth on
Seepage Rate
Inner Ring
Bellvue Laboratory
Sept. 1952
Legend
o Level Decreasing
□ Level Increasing
Note
Corrected to 60° F
Depth of Water in Feet (d)
Seepage Rate in Feet per Day (q)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
0
.10
.20
.30
.40
.50
.60
.70
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, RESEARCH

Figure 13

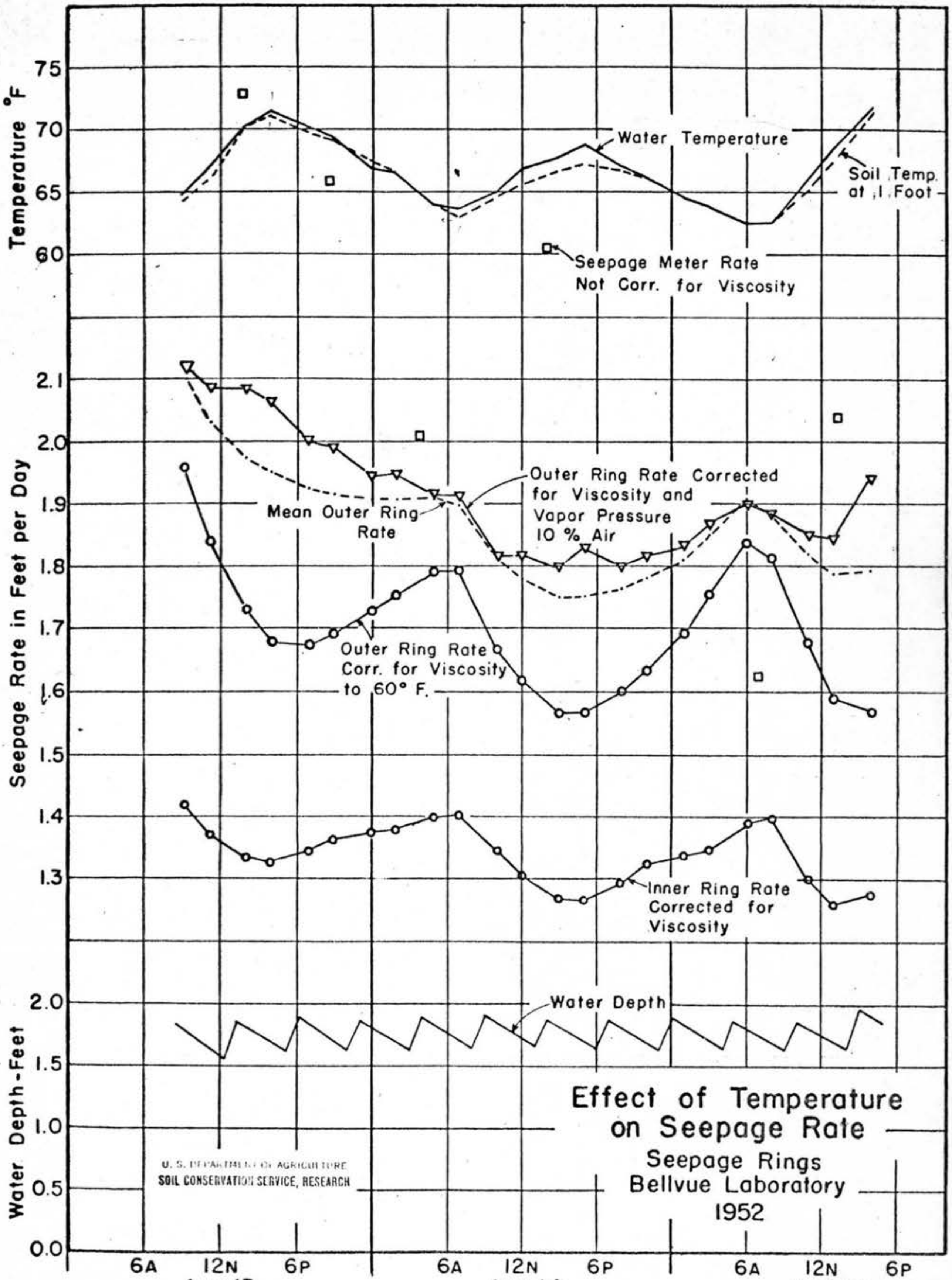

Effect of Depth on
Seepage Rate
Outer Ring
Bellvue Laboratory
Sept. 1952
Depth of Water in Feet (d)
Seepage Rate in Feet per Day (q)
Legend
o Level Decreasing
□ Level Increasing
Note
Corrected to 60° F
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, RESEARCH
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4

The plots show that the seepage rates, when the levels were being successively dropped, were higher for a corresponding depth than when they were being successively raised. An average of these two rates probably gives a rate which could be considered free of drainage and storage effects. The plot for the inner ring shows that the rate of change of the seepage was smaller than that for the outer ring. However, by projecting the average rate until zero depth was reached a rate of approximately 0.1 foot per day was common for both tests. This value is the equivalent of the permeability K.

A test was made in August to determine the effect of temperature on the seepage rate. For this test the water was shut off and readings of the seepage loss were taken at two-hour intervals continuously over a period of three days by noting the drop in the water surface. After each four-hour period the rings were refilled in order to minimize the effect of change in water depth. In addition to noting the drop in water surface level, the water and soil temperature were recorded. Figure 14 is a plot of the results. The seepage rates shown have been corrected to eliminate the effect of variations in depth.

This plot shows that there was a definite variation in the seepage rates over a short period. When the viscosity correction was applied to eliminate the effect of viscosity due to differences in temperature the variation was even more pronounced. The highest seepage rates occurred when the temperature of the water

Sand Figure 14



Effect of Temperature on Seepage Rate

Seepage Rings
Bellvue Laboratory
1952

was lowest and the lowest rates at the highest temperature. (See figure 14.)

Apparently there is another factor, dependent on temperature, that affects the seepage rate. Because some air in the form of small bubbles, remains in the soil even after long periods of wetting, it may have a variable effect on the seepage as the temperature changes. Air should be absorbed as the water cools and should be released as the water warms. Whether the water was getting warmer or colder as it traveled down through the soil was indicated by the soil thermometers in the rings. Analysis of the data however, disclosed the fact that generally the seepage decreased when air was being absorbed and increased when air was being released by the water. Since this is contrary to what should be expected other factors were investigated.

The effect of expansion of air with temperature was studied but it was found that the expansion for the range of temperatures encountered was so small that it would not account for the differences noted.

It has been suggested that changes in vapor pressure with temperature may affect the seepage rate. Because the vapor pressure changes rapidly as the temperature increases, air bubbles should expand and contract appreciably, thereby changing the effective porosity of the soil. It has been demonstrated by Fair and Hatch (3) that the permeability K of granular materials is proportional to $\frac{n^3}{(1-n)^2}$, where n is the porosity of the material.

Small changes in porosity produce large changes in permeability and consequently in the seepage rate. Since the change in volume of the air bubbles is directly proportional to the change in pressure, the change in porosity can be computed if the percentage of air and the temperature are known. Unfortunately the percentage of air is unknown and it cannot be readily determined. However it is possible to determine the relative effect of the change in vapor pressure on the porosity by assuming the percentage of air in the soil.

A computation of the effect of change in vapor pressure on the seepage was made on the assumption that at 60° F, 10 percent of the voids in the sand were filled with air. The effect of the change in porosity at any other temperature was then computed by the formula $K \propto \frac{n^3}{(1-n)^2}$. The temperature of the water at the bottom of the rings was used in the computations. By applying the corrections for the different temperatures to the seepage corrected for viscosity, the curve shown in figure 14 was obtained. The interesting thing to note is that when the seepage is corrected for changes in viscosity and porosity due to temperature, the curve obtained is very close to the one for the seepage as actually observed, that is, without any temperature corrections. This indicates that the effects of viscosity and porosity on the seepage as the temperature changes, are compensating factors.

These conclusions are confirmed by tests on the permeability of sand at widely different temperatures by Pillsbury (6).

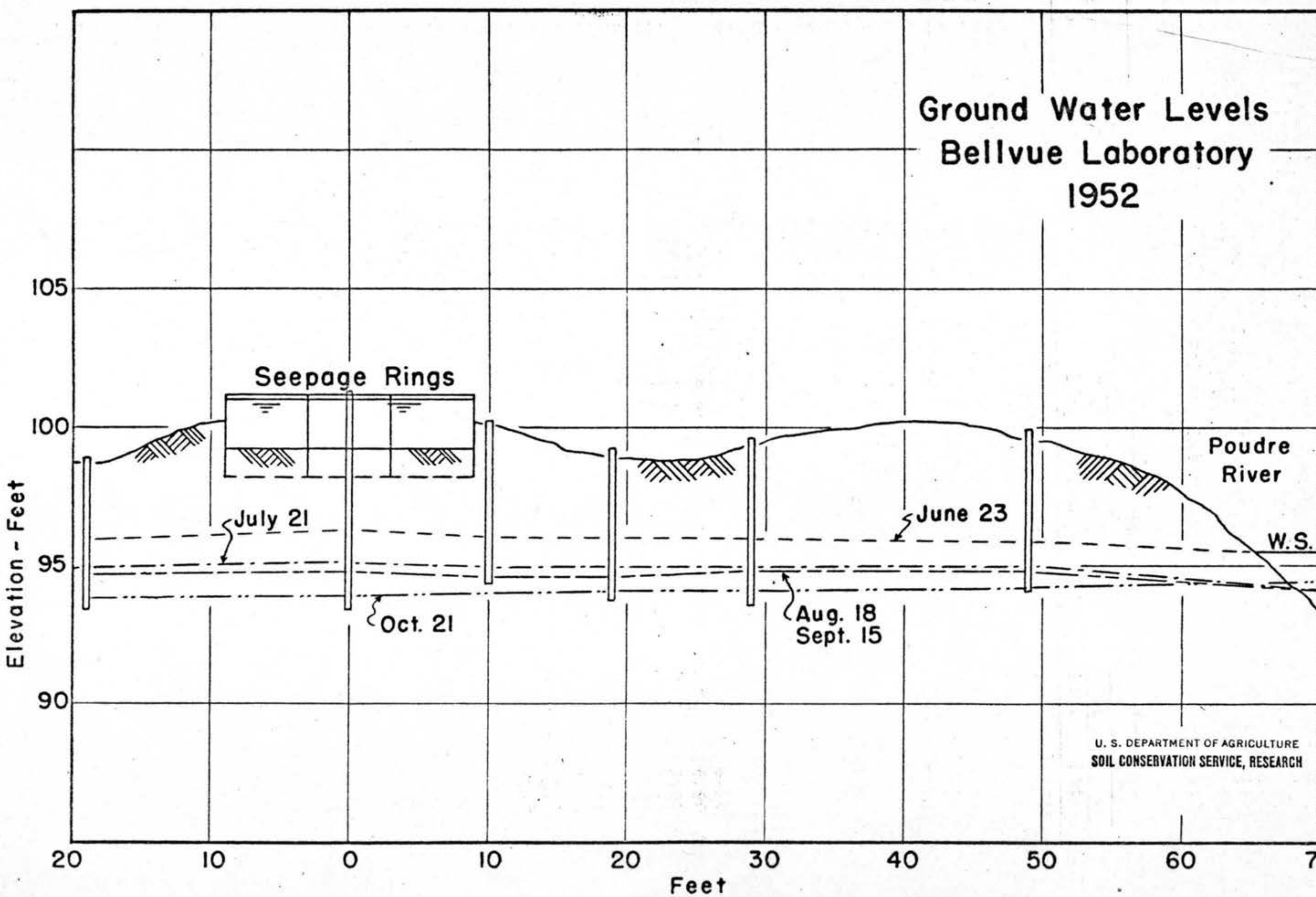
His tests show that increasing the temperature of the water from 40° F to 120° F did not change the permeability. In making the computations for the corrections due to temperature, it was noted that the product of the viscosity correction factor and the porosity correction factor was a constant. This should of course occur if the two effects are compensating. The conclusion that can be drawn from this study is that the results will probably be just as satisfactory if no corrections are applied for the effect of temperature.

Weekly measurements were made of the ground water elevation in the vicinity of the seepage rings. A plot showing the water table at monthly intervals is shown in Figure 15. As in previous years the ground water fluctuation seemed to be due only to the change of stage of the Poudre River nearby.

Seepage Meters

During the 1952 season over 80 determinations of seepage rates were made with the two types of seepage meters at the Bellvue Laboratory seepage rings. These meters were generally installed side by side in the outer ring with the meters remaining in one location about two weeks. The first tests were usually made within a day after placing the meter.

The results of the tests are tabulated in table 4 and are plotted in figure 11. The seepage meters always gave rates which were higher than those shown by the seepage rings and in many cases several times higher. The rates immediately after



Ground Water Levels
Bellvue Laboratory
1952
Seepage Rings
Poudre
River
W.S.
June 23
July 21
Oct. 21
Aug. 18
Sept. 15
Elevation - Feet
105
100
95
90
20
10
0
10
20
30
40
50
60
70
Feet
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, RESEARCH

Figure 15

Table 4.-- Comparison of Seepage Ring and Seepage Meter Measurements of Seepage Bellvue Laboratory 1952

Time	Water Depth	Seepage Rings		Seepage Meters			
		Inner Ring	Outer Ring	SCS		USBR	
				Loc.	Rate	Loc.	Rate
	Ft.	Ft/day	Ft/day		Ft/day		Ft/day
7-18	1.88	5.34	10.80	1	55.5	A	36.9
7-21	2.01	4.41	7.10	1	30.2	A	17.2
7-22	1.95	18.00*	19.00*	1	12.4	-	--
7-24	1.50	14.10	14.10	1	14.4	B	30.0
7-25	1.92	11.53	11.58	1	15.8	B	26.4
7-28	1.97	5.24	6.91	1	11.2	B	16.3
7-30	1.87	4.61	6.03	1	9.72	B	14.1
8-1	1.66	4.24	5.19	1	9.48	B	12.2
8-5	1.88	2.67	3.29	1	7.00	B	8.30
8-6	1.86	2.10	3.23	2	8.78	C	4.14
8-8	1.79	2.19	2.81	2	5.36	C	4.90
8-11	1.85	1.95	2.62	2	4.79	C	2.03
8-13	1.81	1.57	2.00	-	--	C	2.56
8-13	1.68	1.59	1.96	-	--	C	2.42
8-14	1.85	1.52	1.96	-	--	C	2.07
8-14	1.84	1.45	1.81	-	--	C	2.31
8-15	1.70=	1.41	1.83	-	--	C	1.63
8-15	1.62	1.36	1.68	-	--	C	2.04
8-18	1.83	1.48	1.79	2	3.97	C	2.33
8-20	1.87	1.29	1.81	3	9.25	D	17.20
8-22	1.88	1.10	1.45	3	6.30	D	9.65
8-25	1.88	1.02	1.26	3	6.24	D	6.62
8-26	1.88	1.17	0.86	3	5.58	D	5.53
8-27	1.88	0.90	1.10	-	--	D	7.35
8-28	1.89	1.05	1.14	3	25.4**	D	5.50
8-29	1.89	0.93	1.10	3	13.4	D	4.21
9-2	1.89	0.63	0.93	3	7.32	D	2.28

Table 4.-- Comparison of Seepage Ring and Seepage Meter Measurements of Seepage Bellvue Laboratory (Continued) 1952

Time	Water Depth	Seepage Rings		Seepage Meters			
		Inner Ring	Outer Ring	SCS		USBR	
				Loc.	Rate	Loc.	Rate
	Ft.	Ft/day	Ft/day		Ft/day		Ft/day
9-15	1.88	1.90*	3.10*	4	37.8	E	24.6
9-17	1.88	1.36	2.19	4	23.4	E	20.4
9-19	1.88	1.33	2.78	4	10.8	E	10.9
9-22	1.88	1.26	1.74	4	8.26	E	9.13
9-24	1.88	1.10	1.53	4	6.80	E	7.66
9-26	1.88	0.93	1.38	4	5.37	E	6.16
9-29	1.89	0.81	1.27	4	4.14	E	4.53
10-1	1.89	0.76	1.12	4	3.34	E	3.74
10-3	1.89	0.67	1.05	4	2.92	E	3.24
10-6	1.90	0.72	1.00	4	2.26	E	2.93
10-8	1.90	0.57	0.90	4	2.14	E	2.25
10-10	1.90	0.57	0.95	4	2.13	E	2.08
10-13	1.90	0.55	0.81	4	1.88	E	2.10
10-15	1.89	0.50	1.24	5	39.0	F	19.5
10-17	--	0.50	0.98	5	15.2	F	7.66
10-20	1.90	0.52	0.90	5	7.40	F	3.82
10-22	1.90	0.57	0.81	5	5.53	F	3.18

*Soil raked

**Seepage meter pushed down

installation were very high with a gradual decrease throughout the series. Tests made during the effect of temperature tests on the seepage rings over short time intervals (see figure 14) also showed considerable variation.

Seepage Ring for Study of Effect of Ground Water Fluctuation

As previously described, special equipment was constructed for the purpose of determining the effect of the depth to ground water on the seepage rate. This equipment is shown in figures 6 and 16. The soil used was the same as had been used in the seepage rings during the two previous seasons. A report of the characteristics of this soil is contained in the progress report submitted in 1951 (7) and the results are tabulated in tables 5, 6 and 7. The mechanical analysis of the soil, figure 17 and table 5, showed it to be sandy loam. According to the Atterburg Classification Index the soil was classed as friable. A chemical analysis of the soil showed it to be alkaline in reaction with very low soluble salt content and no gypsum. The water which was taken from the Poudre River had a very low salt content (see table 3). Permeability tests of disturbed samples shown in figure 18 indicated a permeability of between 4 and 5 feet per day for the soil.

Water was first turned into the ring on July 9 and continuous operation was maintained until October 23. Figure 19 is a plot of the results. After an initial period of approximately 20 days the ground water levels were changed weekly except for the last month when the levels were changed every four days. The water

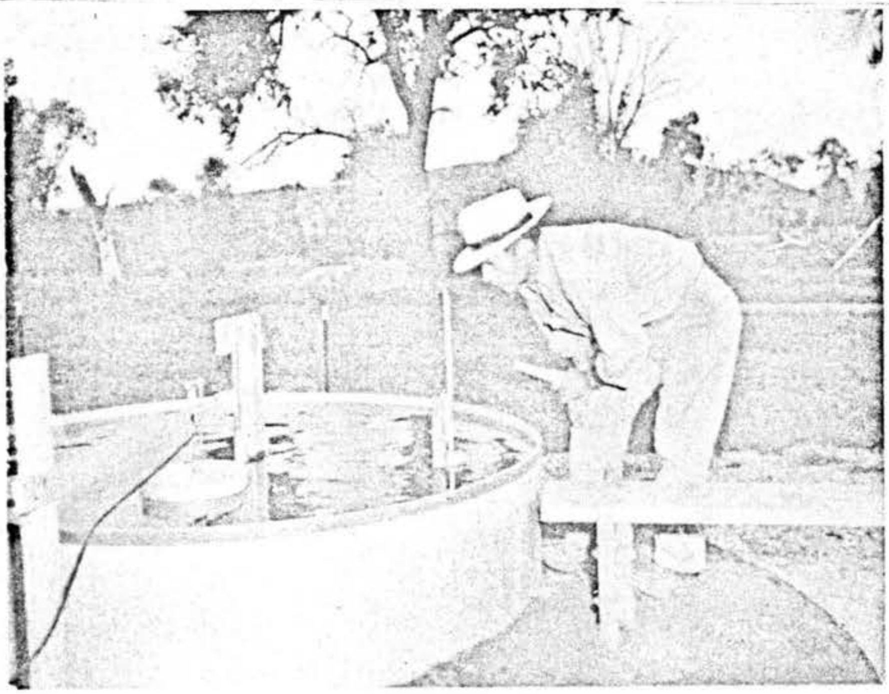


Figure 16.-- Equipment for study of effect of ground water level on seepage.

Table 5.-- Combined Mechanical Analysis of Soils
Effect of Water Table Elevation
Bellvue Laboratory
1952

Sample Location	Colloids .001 mm	Clay .001-.005 mm	Silt .005-.05 mm	Fine Sand .05-.25 mm	Coarse Sand .25-2.0 mm	Gravel 2.0 mm	U. S. Bureau of Soils Classification
	Percent	Percent	Percent	Percent	Percent	Percent	
0.0-1.0 Ft.	1	6	20	58	14	1	Sandy Loam
1.0-2.0 Ft.	2	2	18	52	25	1	Sandy Loam

Table 6.-- Chemical Analysis of Soils
Effect of Water Table Elevation
Bellvue Laboratory
1952

Sample Location	pH	Total Soluble Salts	Total Gravimetric Salts	Ca CO_3 (Lime)
		Percent	Percent	Percent
0.0-1.0 Ft.	8.0	.02	0.5	2.3
1.0-2.0 Ft.	7.8	.02	0.5	1.1

Table 7.-- Soil Analysis
Effect of Water Table Elevation
Bellvue Laboratory
1952

Sample Location	Liquid Limit	Plastic Limit	Plasticity Index	Atterburg Classification Index	Bureau of Soils Classification	K Disturbed Perm. Ft/day
0.0-1.0 Ft.	25.8	25.8	0	Friable	Sandy Loam	3.9-4.4
1.0-2.0 Ft.	25.8	25.8	0	Friable	Sandy Loam	4.6-6.0

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, RESEARCH

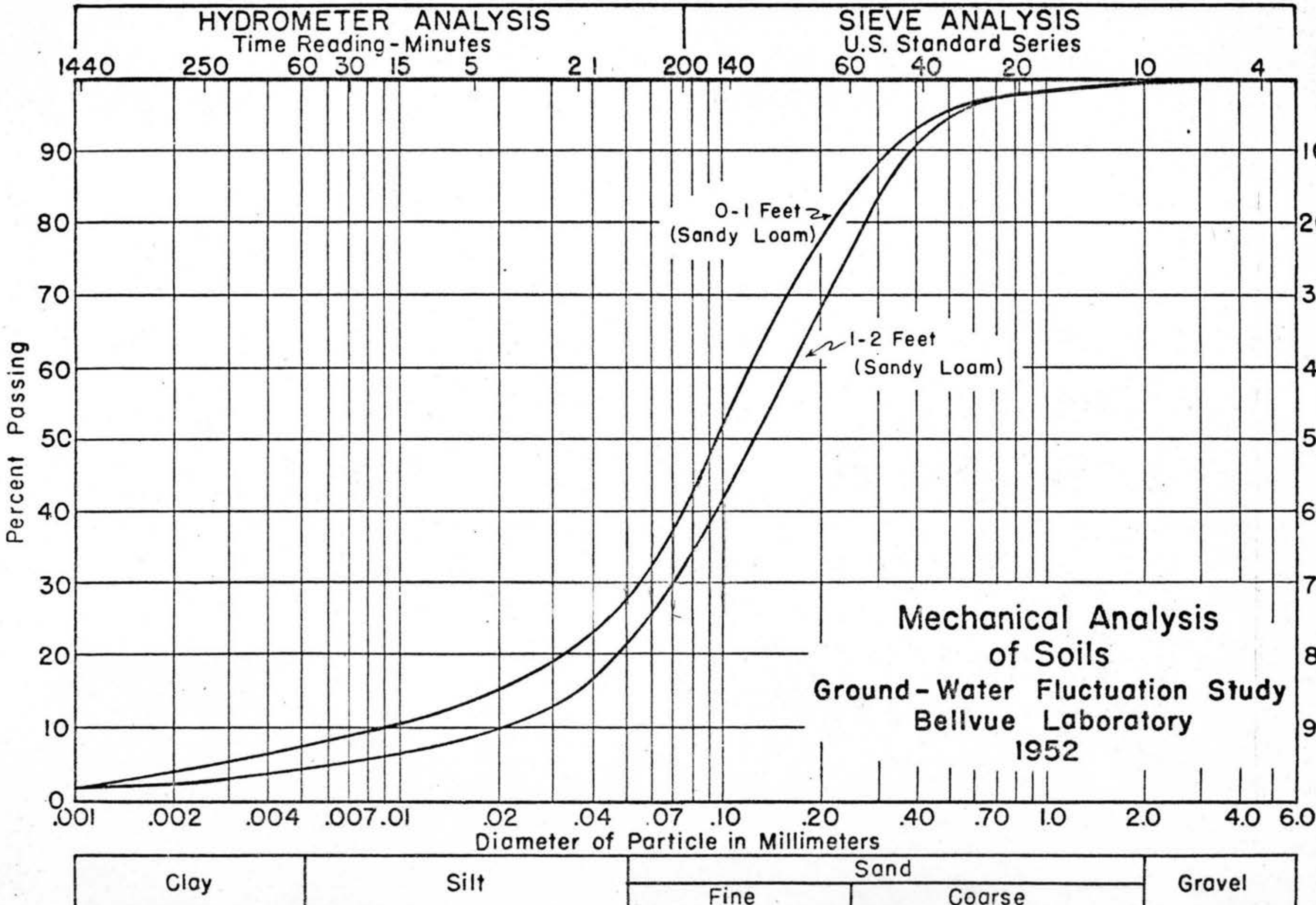


Figure 17

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, RESEARCH

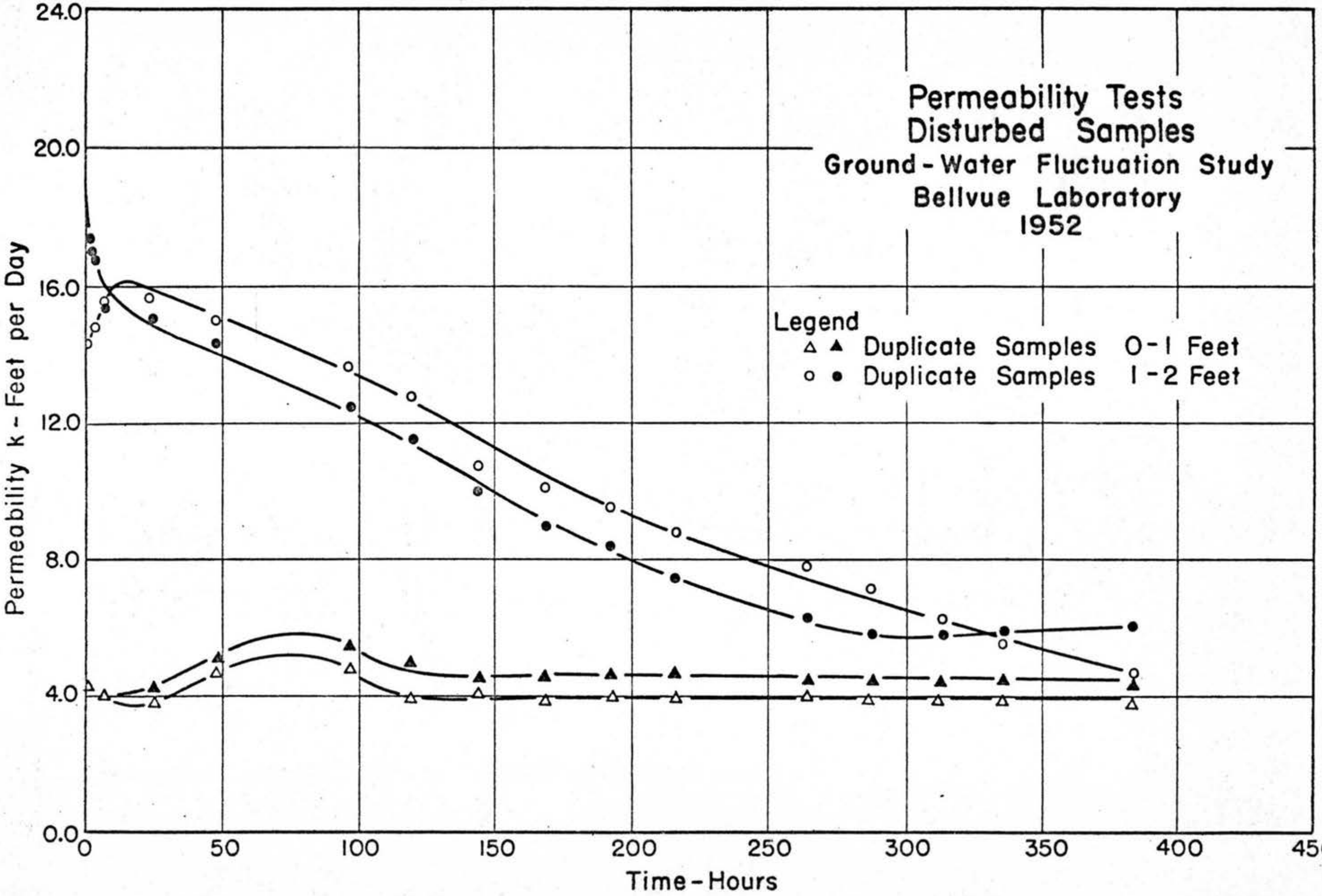


Figure 18

Figure 19

Seepage Ring for Study of Effect of Ground-Water Fluctuation
Bellvue Laboratory
1952

depth in the ring was kept constant at about 1.9 feet except for a short initial period.

The initial seepage rate was 1.1 feet per day with an immediate decrease to 0.5 foot per day. After the water depth was increased the seepage rate began a gradual increase until a maximum rate of 1.7 feet was reached. There was a general decrease from this point until the end of the period when a rate of 0.3 foot per day was reached. Difficulty was encountered in separating the effect of the fluctuating ground water elevations and other factors on the seepage rates. Leaks from the ring probably caused by earth worms, frequently occurred. Factors such as air solution and bacteriological action (1), (2), which normally cause variations of seepage rates, could not be isolated.

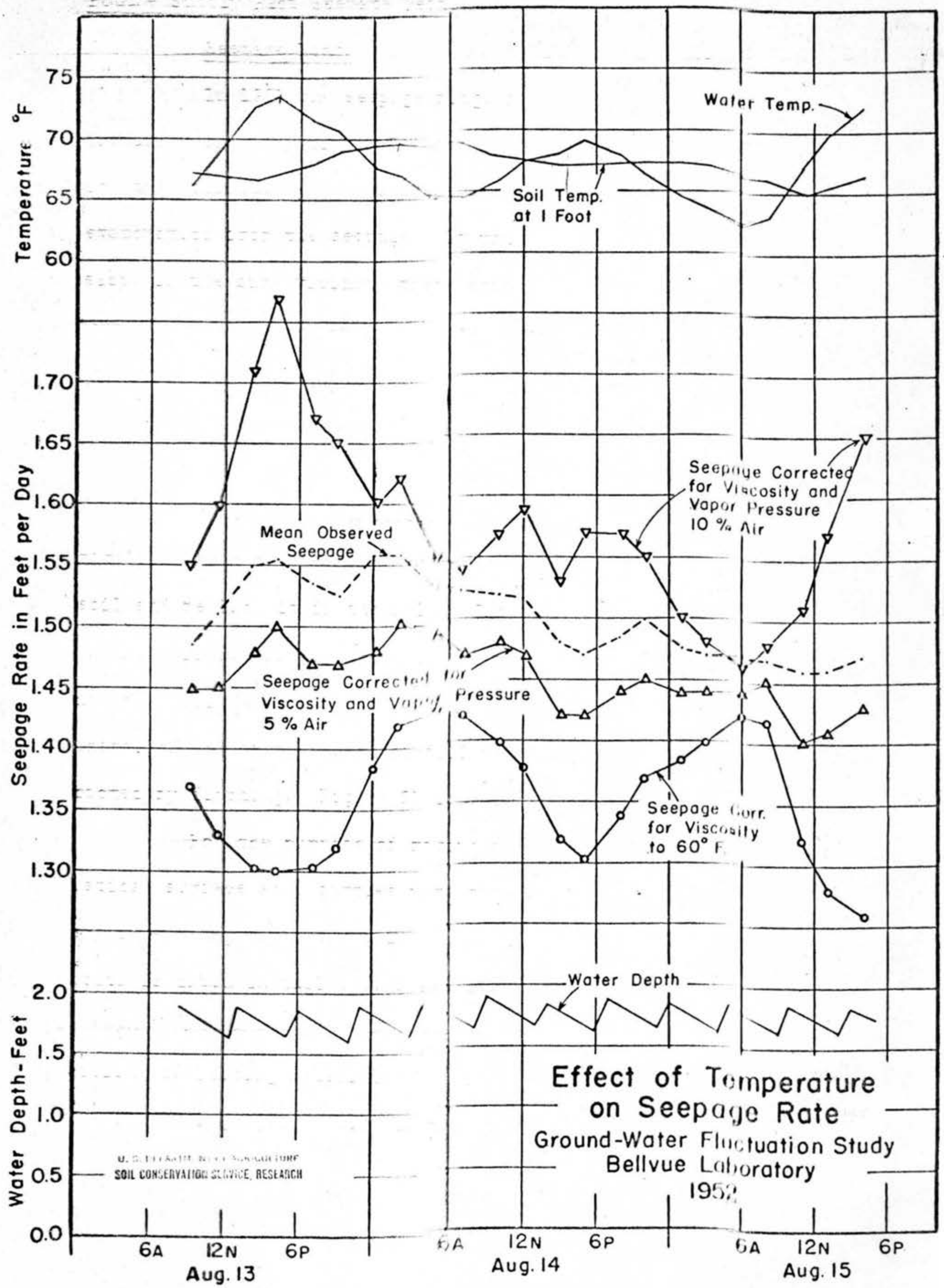
Generally, it was noted that as the ground water level approached the ground surface there was a decrease in seepage. If only the data for the day preceding and the day following an adjustment in ground water level were considered, a marked change in the seepage rate for this period was apparent. As the water table was raised the seepage rate decreased on an average of 13 percent from its previous rate for each 6-inch increment. For a lowering water table the rates increased for each increment an average of 32 percent. However, during the periods of constant ground water levels, there was a gradual decrease of rates.

During August a test was made to determine the effect of temperature on the seepage rate. This test was made over a period of three days with readings made at two hour increments. Observations included the water depth and the water and soil temperatures. Figure 20 is a plot of the results. This plot shows that there was a variation in rates over the period of a maximum of 11 percent for comparable depths of water. The maximum rates were observed at the time the water temperatures were the lowest and, conversely, the lowest rates at the highest temperatures. Considering the soil temperatures and the direction of the temperature gradients the foregoing relationship should have been reversed.

The effect of temperature on the porosity due to the expansion and contraction of the air bubbles in the soil with changes in vapor pressure, was investigated by the method discussed on pages 14 to 17. The water temperatures were used in making the corrections. Computations were made on the assumption that the soil contained 10 percent air and similar computation on the assumption that it contained 5 percent air. The seepage rates corrected for the effect of viscosity and porosity are shown plotted in figure 20. In this case the curve based on the assumption that the soil contained 5 percent air, follows the original seepage data very closely, whereas the curve for 10 percent air deviates considerably. This indicates that the percent of air actually in the soil was probably somewhere between 5 and 10. It is apparent that means must be found for determining the amount of air in the soil before the effect of temperature on the seepage can be eliminated.

Silt

Figure 20



Effect of Temperature on Seepage Rate

Ground-Water Fluctuation Study

Bellvue Laboratory

1952

Poudre Supply Plot Seepage Tests

Seepage Rings

In 1951 the seepage rings at the Poudre Supply Plot were installed in heavy clay. The permeability of this material was so low that difficulty was encountered at times in separating the evaporation from the seepage. It was found that farther up the slope in the same vicinity there existed a material which was more permeable and it was decided to move the seepage rings to this new location. In making the required excavation for the installation of the rings, channels of material of an entirely different type were found indicating the existance of an old prairie dog colony. For this reason it was necessary to excavate a large hole, approximately 20 feet in diameter and three feet deep, thoroughly mix the soil and replace it in the hole. The mixed soil was put back in the hole in layers, settling each layer with water. After the hole had been filled to a depth of two feet the seepage rings were installed and another foot of soil was put into the rings and compacted by flooding. Figure 21 is a picture of the installation.

For the purpose of making a study of the soil characteristics, surface soil samples were taken at three locations around the outer ring after the soil was replaced. A summary of these tests is given in tables 8, 9 and 10. The mechanical analysis of the soil was made using the procedure presented by the American Society of Testing Materials. Sodium silicate was again used as the dispersing agent. Size distribution curves for each sampling

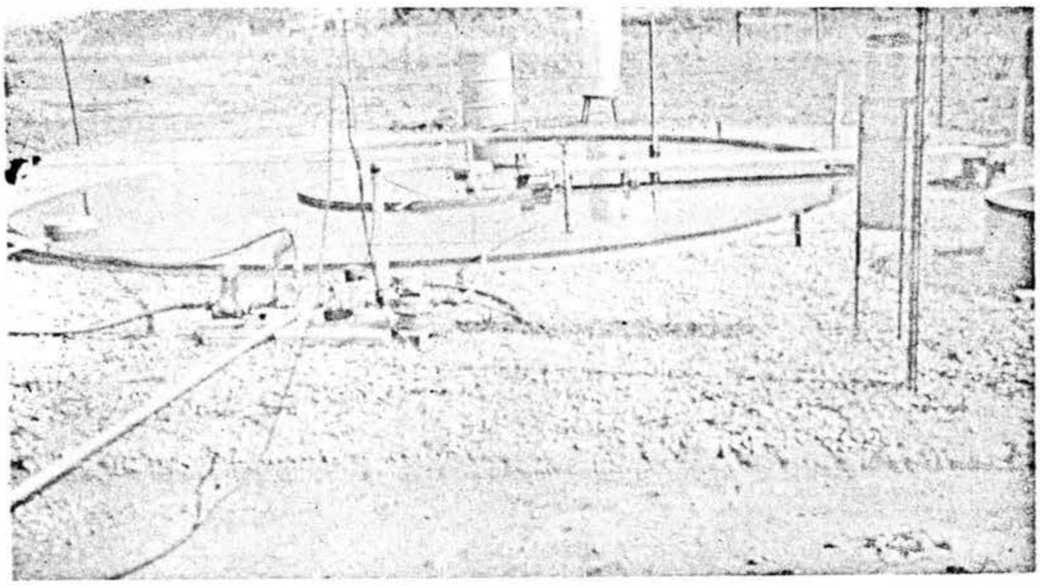


Figure 21.-- Seepage Rings, Poudre Supply Plot

Table 8.-- Combined Mechanical Analysis of Soils
Seepage Rings, Poudre Supply Plot
1952

Sample Location	Colloids .001 mm	Clay .001-.005 mm	Silt .005-.05 mm	Fine Sand .05-.25 mm	Coarse Sand .25-2.0 mm	Gravel 2.0 mm	U. S. Bureau of Soils Classification
	Percent	Percent	Percent	Percent	Percent	Percent	
NW Side	1.0	7.0	24.0	26.0	42.0	0.0	Sandy Loam
E Side	1.0	5.0	23.0	33.0	38.0	0.0	Sandy Loam
SW Side	1.0	5.0	21.5	39.5	33.0	0.0	Sandy Loam

Table 9.-- Chemical Analysis of Soils
Seepage Rings, Poudre Supply Plot
1952

Sample Location	pH	Total Soluble Salts	Total Gravimetric Salts	Organic Material	$CaCO_3$ (Lime)
		Percent	Percent	Percent	Percent
NW Side	8.1	.13	0.5	0.5	14.6
E Side	8.5	.02	0.5	0.4	14.0
SW Side	9.0	.02	0.5	0.5	13.9

Table 10.-- Soil Analysis
Seepage Rings, Poudre Supply Plot
1952

Sample Location	Liquid Limit	Plastic Limit	Plasticity Index	Atterburg Classification Index	Bureau of Soils Classification	K Disturbed Perm.
						Ft/day
NW Side	26.1	18.8	7.3	Feebly Plastic	Sandy Loam	1.60
E Side	26.8	16.0	10.8	Feebly Plastic	Sandy Loam	1.25
SW Side	26.8	17.1	9.7	Feebly Plastic	Sandy Loam	1.10

location are shown in figure 22 and a summary is given in table 8. The three samples were classified as sandy loam and their size distribution was very nearly the same.

A chemical analysis of the soil is given in table 9. This shows that the soils were alkaline in reaction, samples from two locations being strongly alkaline. The total soluble salt content is low and no gypsum is indicated. The organic material content is very low but the lime content of all samples is high.

The liquid limit, plastic limit, and plasticity index were determined in accordance with methods set forth by the American Society of Testing Materials. Table 10 shows the results of these tests. Using the Atterburg Classification Index the soils were all classified as feebly plastic.

An analysis of the water which was taken from the Fort Collins City water line is shown in table 3. This water contains a low percentage of impurities and should have no effect on the permeability of the soils.

Permeability tests of disturbed soil samples are shown on figure 23. These tests were made using the procedure previously described. These plots show a range of permeabilities for the three samples of from 1.10 to 1.60 with an average of 1.30 feet per day. These values were determined at the end of a 16-day period.

Water was first turned into the rings on June 12 and continuous readings were taken until October 21. In addition to

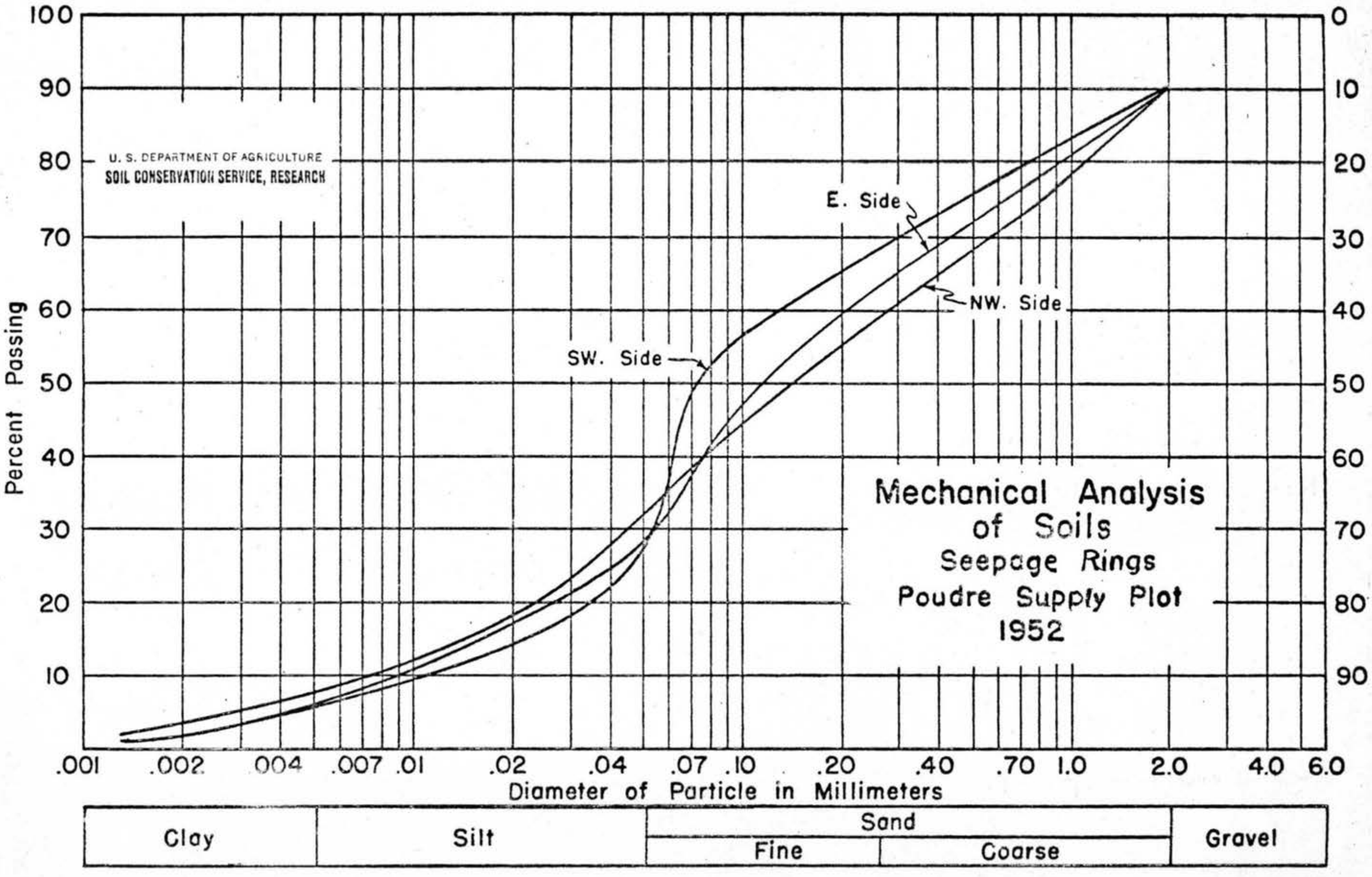
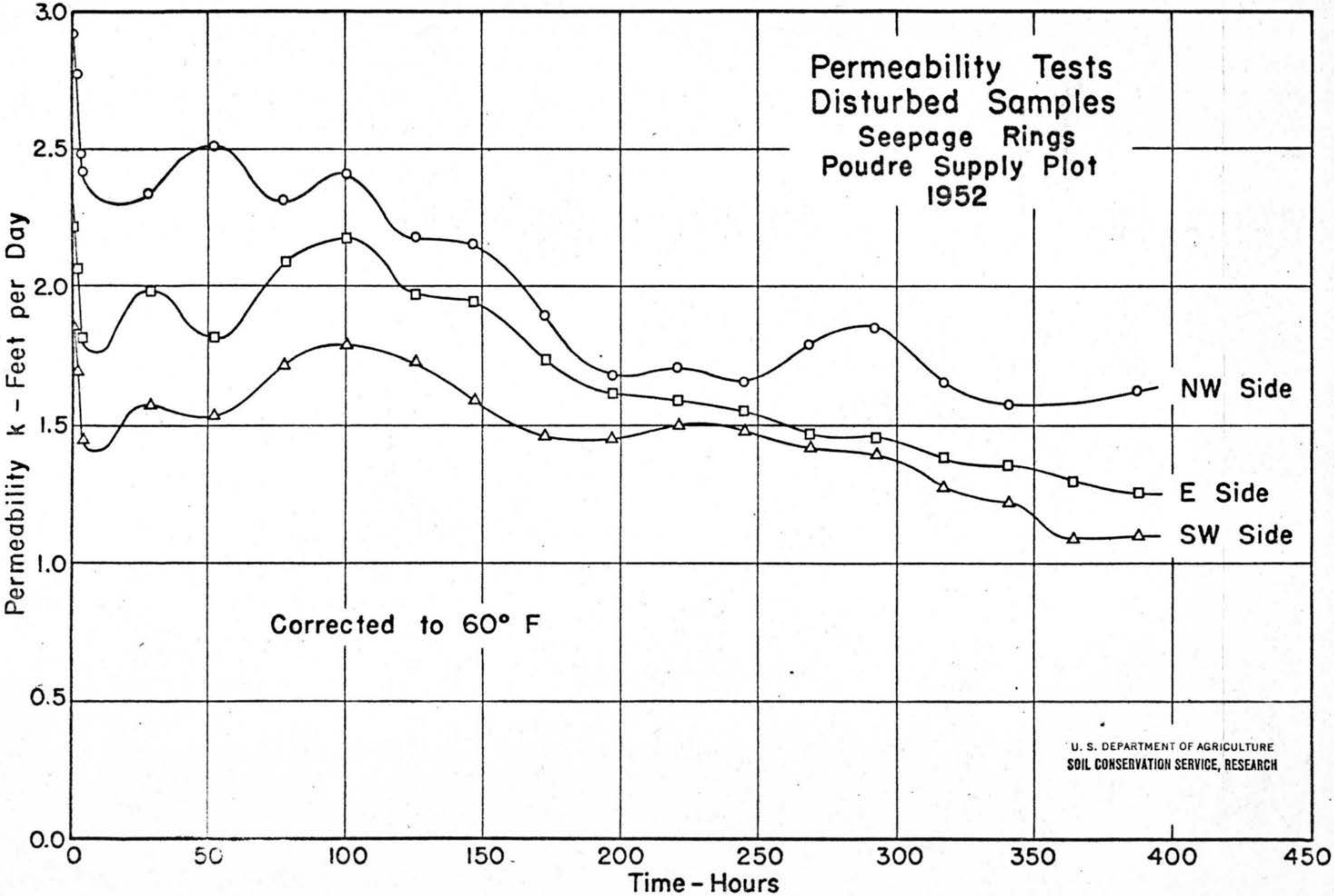

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, RESEARCH
Mechanical Analysis of Soils
Seepage Rings
Poudre Supply Plot
1952
E. Side
NW. Side
SW. Side
Percent Passing
Percent Retained
Diameter of Particle in Millimeters
Clay
Silt
Sand
Fine
Coarse
Gravel

Figure 22

the readings taken as at the Bellvue rings, the rate of evaporation was observed from a Weather Bureau Class A evaporation pan. Approximately three times a week the water was cut off and seepage determinations made by observing the drop in water surface elevation. A magnetic valve to control the flow was installed for the inner ring after the seepage rate dropped so low that the conventional meter would not operate.

A plot of the seepage rates and other observed data is shown in figure 24. The initial seepage rate for the outer ring was approximately 1.1 feet per day and that for the inner ring 0.9 foot per day. There was a general decrease in rates for approximately one month after which the rates started to increase until a maximum rate of approximately 0.95 for the inner ring and 1.4 feet per day for the outer ring was reached. This occurred after approximately three months of operation. After this point there was a general decrease in rates until the termination of the tests. The results of the drop tests check very close to those shown for the continuous data. The 1-foot soil temperatures at this location did not follow the water temperatures as was the case at Bellvue. They more nearly followed an average of the water temperatures.

In order to determine the effect of depth of water on the seepage rate a series of tests was made during the period of September 2 to 10. Plots of these tests are shown in figures 25 and 26. In contrast with the tests made at Bellvue, these tests show that the rates when the levels were increasing were greater than

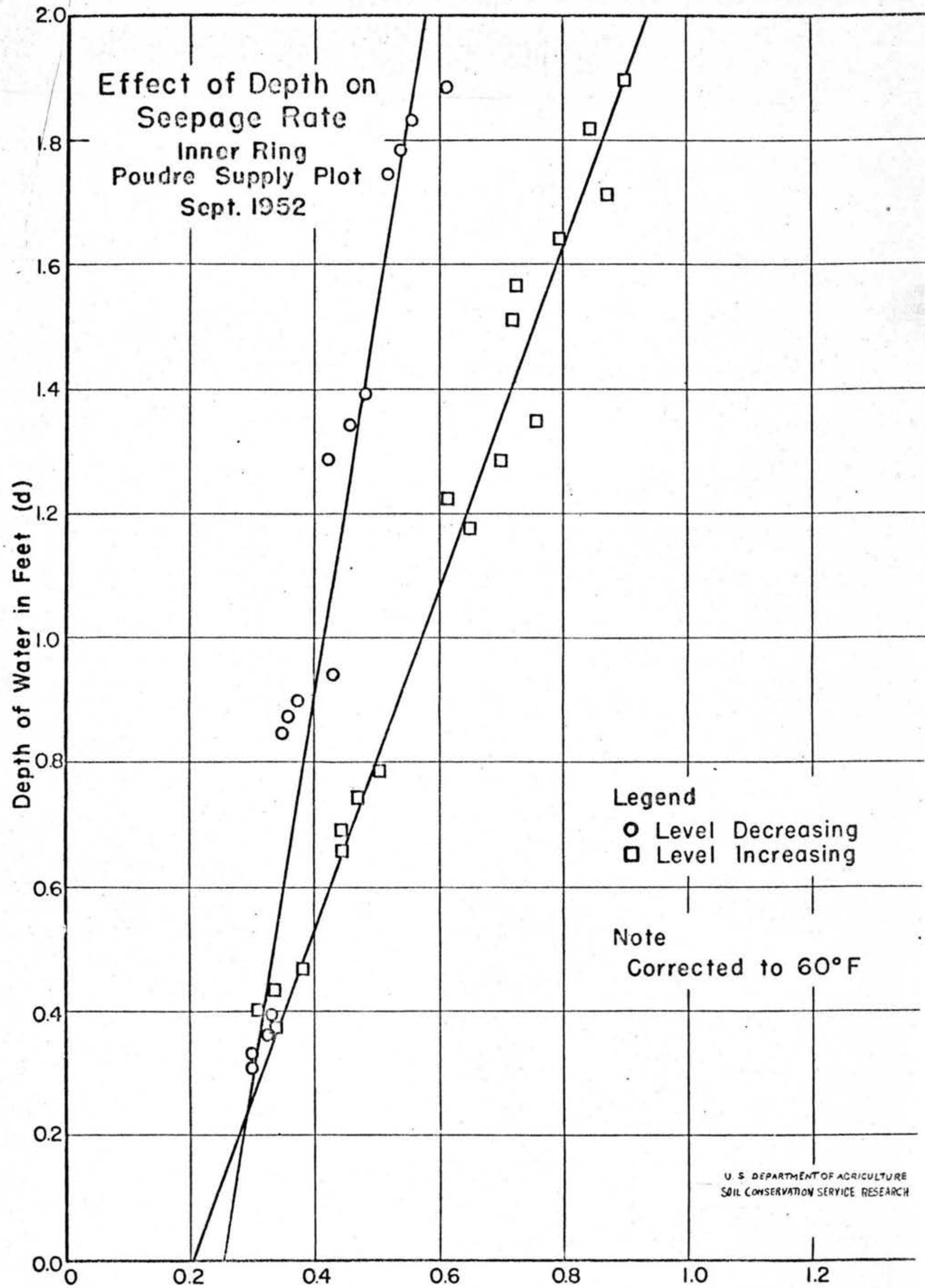


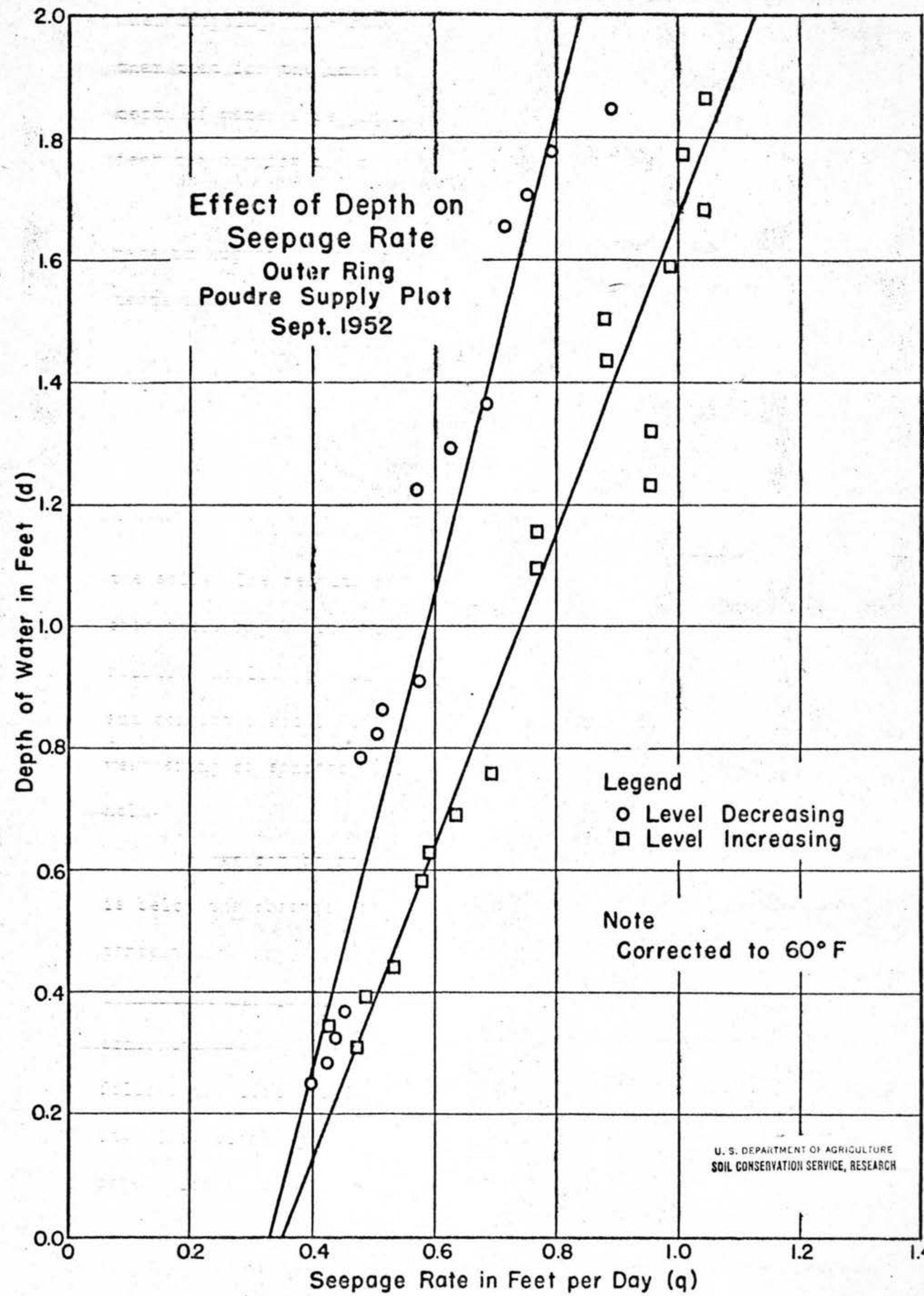
Permeability Tests
Disturbed Samples
Seepage Rings
Poudre Supply Plot
1952
Permeability k - Feet per Day
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
50
100
150
200
250
300
350
400
450
Time - Hours
NW Side
E Side
SW Side
Corrected to 60° F
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, RESEARCH

Figure 23

Figure 24

Barometric Pressure
Soil Temperature at One Foot
Water Temperature - Bottom
Seepage Rate - Outer Ring
Seepage Rate - Inner Ring
Water Depth
Water off in line
Outer Ring valve leaking
Bottom raked
Two holes plugged
Three holes plugged Outer Ring
Large hole plugged
Legend
Drop Test - Outer Ring
Drop Test - Inner Ring
S.C.S. Seepage Meter
U.S.B.R. Seepage Meter
Inches - Mercury
Temperature °F
Seepage - Feet per Day
Water Depth Feet
June
July
August
September
October
Seepage Rings
Poudre Supply Plot
1952

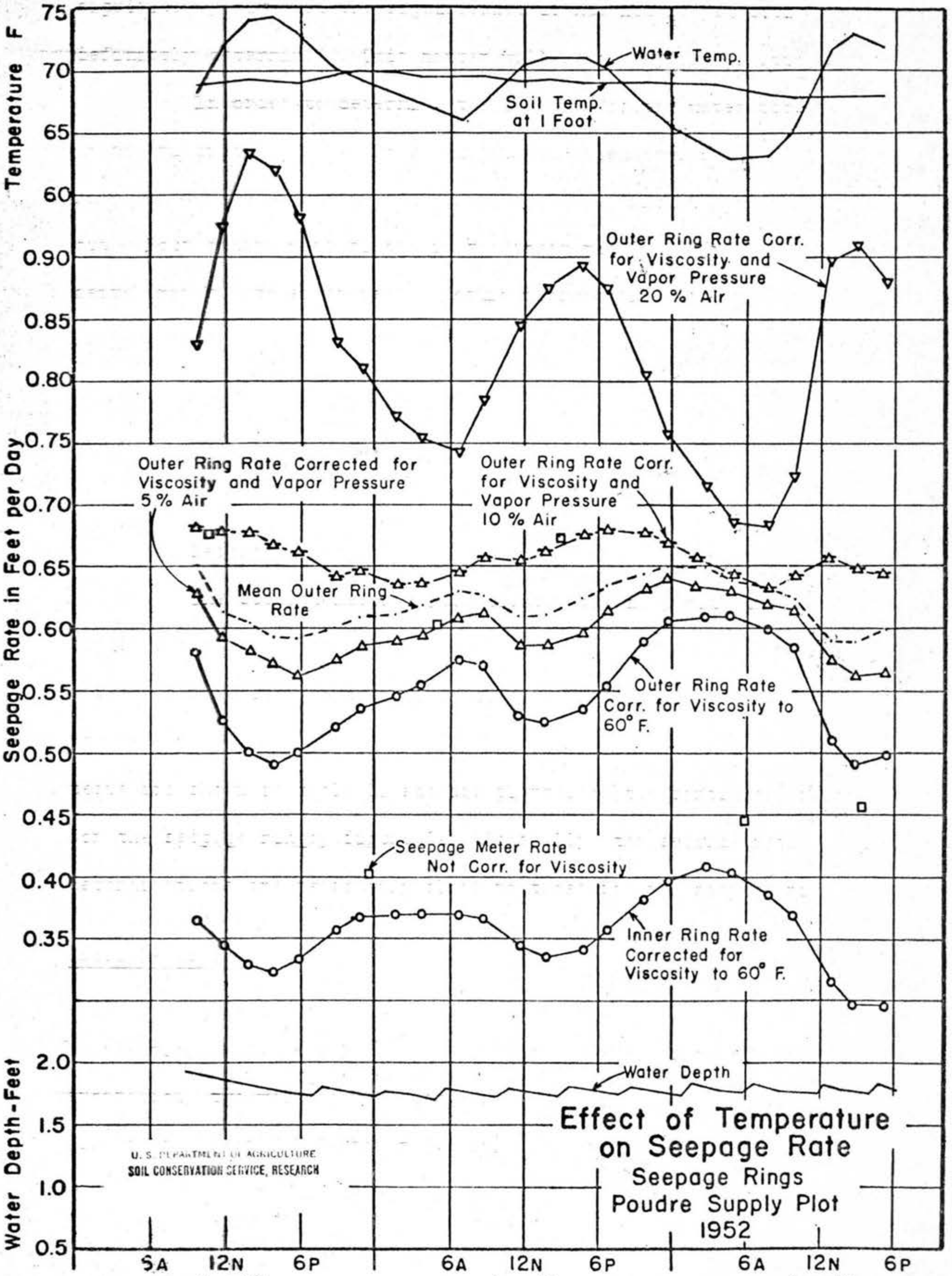

Effect of Depth on
Seepage Rate
Inner Ring
Poudre Supply Plot
Sept. 1952
Depth of Water in Feet (d)
Seepage Rate in Feet per Day (q)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
0
0.2
0.4
0.6
0.8
1.0
1.2
Legend
O Level Decreasing
□ Level Increasing
Note
Corrected to 60° F
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE RESEARCH


Effect of Depth on
Seepage Rate
Outer Ring
Poudre Supply Plot
Sept. 1952
Depth of Water in Feet (d)
Seepage Rate in Feet per Day (q)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
Legend
o Level Decreasing
□ Level Increasing
Note
Corrected to 60° F
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, RESEARCH

when dropping. The rate of change for the outer ring was greater than that for the inner ring as was the case at Bellvue. At zero depth of water a seepage rate of 0.23 for the inner ring and 0.34 feet per day for the outer ring is indicated.

The tests to determine the effect of temperature were made in August and the results are shown in figure 27. These tests also, show that when the seepage was corrected for the effect of change in viscosity with temperature, the resulting seepage rates were low when the temperature was high and vice versa. For this reason the effect of temperature on the porosity was investigated in the manner previously explained. (See pages 14 to 17.) Computations were made on the basis of 5, 10 and 20 percent air in the soil. The results are shown plotted in figure 27. In this case there may be some question as to whether the Fair-Hatch (3) relation applies but since the material was only feebly plastic and consisted mostly of fine sand and silt resulting from the weathering of sandstone, it was assumed that the relation should hold.

As can be seen in the figure the curve for 5 percent air is below the observed seepage rate whereas the curves for 10 and 20 percent air, are above the observed seepage rate, and the curve for 20 percent air is widely separated. Evidently the true value is somewhere between 5 and 10 percent. The curve for 5 percent air follows the observed seepage very closely and only slightly below it. This close agreement is apparent for the tests at three different locations with three different materials. It must be



Effect of Temperature on Seepage Rate
Seepage Rings
Poudre Supply Plot
1952

significant, but what the significance is has not as yet been definitely determined. This matter will be given further study.

In order to determine the location of the water table in the vicinity of the seepage rings, four piezometers, 8 feet long were installed 10 feet out from the outer ring and one, 1-foot out. Four others were placed in the inner ring which ranged in depth from two to eight feet. Weekly measurements were made at each piezometer. During the entire testing season there was no free water in any of the piezometers except the one at two feet depth in the inner ring. It was thought that the water was leaking down and around this piezometer.

Seepage Meters

The seepage meter measurements were made with the two types of seepage meters installed side by side in the outer ring using the procedure as previously described. Generally the meters were moved to a new location every two weeks. The results of these tests are shown in table 11 and are plotted on the continuous record for the seepage rings, figure 24. Generally, the seepage meter determinations are reasonably close to those for the seepage rings.

Canal X-Section

The short canal section shown in figure 7 was excavated in the vicinity of the Poudre Supply Plot seepage rings. Before excavation, two well permeameter tests were made along the center line of the section. After the section had been excavated water

Table 11.-- Comparison of Seepage Ring and Seepage Meter Measurements of Seepage
Poudre Supply Plot
1952

Date	Water Depth	Seepage Rings		Seepage Meters			
		Inner Ring	Outer Ring	SCS		USBR	
				Loc.	Rate	Loc.	Rate
	Ft.	Ft/day	Ft/day		Ft/day		Ft/day
7-2	1.85	0.366	0.431	A	0.359	1	0.365
7-3	1.85	.351	.444	A	.333	1	.322
7-5	1.85	.381	.381	A	.336	1	.382
7-7	1.86	.381	.286	A	.360	1	.598
7-9	1.86	.333	.333	A	.268	1	.603
7-11	1.86	.286	.286	A	.349	1	.608
7-15	1.86	.333	.262	A	.560	1	.812
7-17	1.86	.333	.238	A	.726	1	.901
7-21	1.87	.357	.211	A	.926	1	.823
7-23	1.88	.331	.381	B	.472	2	.246
7-25	1.88	.310	.429	B	.744	2	.392
7-28	1.85	.387	.387	B	.900	2	.612
7-30	1.88	.333	.405	B	.820	2	.594
8-1	1.86	.357	.452	B	.787	2	.662
8-4	1.88	.333	.476	B	.570	2	.780
8-13	1.83	.434	.651	-	--	3	.678
8-13	1.62	.398	.578	-	--	3	.403
8-14	1.69	.398	.602	-	--	3	.602
8-14	1.68	.386	.590	-	--	3	.671
8-15	1.73	.410	.639	-	--	3	.445
8-15	1.70	.373	.614	-	--	3	.458
8-18	1.89	.429	.667	C	1.58	3	.976
8-20	1.90	.524	.762	D	.750	4	1.42
8-22	1.90	.429	.810	D	.826	4	1.55
8-25	1.89	.524	.857	D	.726	4	1.33
8-27	1.90	.643	.929	D	.777	4	1.52
8-30	1.89	.619	.810	D	.602	4	1.25
9-2	1.89	.590	.867	D	.594	4	1.23

Table 11.-- Comparison of Seepage Ring and Seepage Meter Measurements of Seepage Poudre Supply Plot (Continued) 1952

Date	Water Depth	Seepage Rings		Seepage Meters			
		Inner Ring	Outer Ring	SCS		USBR	
				Loc.	Rate	Loc.	Rate
	Ft.	Ft/day	Ft/day		Ft/day		Ft/day
9-15	1.87	0.857	1.048	E	1.52	5	2.97
9-17	1.88	.762	1.286	E	1.18	5	2.08
9-19	1.88	.810	1.238	E	1.00	5	1.40
9-22	1.88	.742	1.129	E	.794	5	1.02
9-24	1.88	.714	1.048	E	.648	5	.872
9-26	1.88	.762	1.024	E	.575	5	1.09
9-29	1.89	.750	1.107	E	.506	5	.980
10-1	1.88	.742	1.032	F	--	6	.415
10-2	1.89	.727	1.087	F	1.56	6	.356
10-3	1.89	.690	1.000	F	1.32	6	.348
10-6	1.88	.714	.810	F	1.14	6	.318
10-8	1.88	.714	.810	F	1.03	6	.296
10-10	1.88	.667	.810	F	1.06	6	.280
10-13	1.88	.774	.839	F	1.14	6	.288
10-15	1.94	.738	.881	F	1.20	6	.276
10-17	1.88	.810	.929	G	3.89	7	4.02
10-20	1.88	.810	.857	G	3.06	7	3.01
10-22	1.88	.857	.762	G	2.65	7	2.77

was turned in the section and continuous ponding tests made for a period of three weeks. The water was then turned off for three weeks after which water was again turned in for over a week. Water used for the experiments was obtained from the Fort Collins City water line.

Soil samples obtained from the section were processed in the laboratory following the procedure previously outlined. The mechanical analysis is tabulated in table 12 and is also shown in figure 28. The U. S. Bureau of Soils classification for this material is sandy loam. The chemical analysis shown in table 13 indicates that the samples are alkaline in reaction and that the lime contents are rather high. The total soluble salt contents are low. The liquid and plastic limits are shown in table 14. The Atterburg Classification indicates the sample from 0.5 - 1.5 feet to be medium plastic and that from 1.5 - 2.5 feet, feebly plastic.

Permeability tests of disturbed soil samples are shown in figure 29. These tests were made in the manner previously described. The samples were tested for approximately 400 hours and the permeability of each sample was very near 1.0 foot per day at the end of this period.

The well permeameter tests were made as prescribed by the U. S. Bureau of Reclamation earth manual (12). Two tests were made at points equally spaced along the center line of the section. The bottom of the test holes corresponded in elevation with the

Table 12.-- Combined Mechanical Analysis of Soils
Canal X-Section, Poudre Supply Plot
1952

Sample Location	Colloids .001 mm	Clay .001-.005 mm	Silt .005-.05 mm	Fine Sand .05-.25 mm	Coarse Sand .25-2.0 mm	Gravel 2.0 mm	U. S. Bureau of Soils Classification
	Percent	Percent	Percent	Percent	Percent	Percent	
0.5-1.5 Ft.	2.0	3.0	40.0	40.0	15.0	0.0	Sandy Loam
1.5-2.5 Ft.	1.0	4.0	44.0	38.0	13.0	0.0	Sandy Loam

Table 13.-- Chemical Analysis of Soils
Canal X-Section, Poudre Supply Plot
1952

Sample Location	pH	Total Soluble Salts	Total Gravimetric Salts	Organic Material	$CaCO_3$ (Lime)
		Percent	Percent	Percent	Percent
0.5-1.5 Ft.	8.2	.09	0.5	1.3	7.5
1.5-2.5 Ft.	8.3	.08	0.5	0.8	6.3

Table 14.-- Soil Analysis
Canal X-Section, Poudre Supply Plot
1952

Sample Location	Liquid Limit	Plastic Limit	Plasticity Index	Atterburg Classification Index	Bureau of Soils Classification	K Disturbed Sample Ft/day	K Well-Perm. Test Ft/day
0.5-1.5 Ft.	32.5	19.6	12.9	Medium Plastic	Sandy Loam	0.48	0.16
1.5-2.5 Ft.	27.3	21.6	5.7	Feebly Plastic	Sandy Loam	0.44	0.16

Table 15.-- Seepage Meter Measurements
Canal X-Section, Poudre Supply Plot
1952

Time	Water Depth	USBR Seepage Meter		SCS Seepage Meter	
		Location	Rate	Location	Rate
	Ft.	Station	Ft/day	Station	Ft/day
8-5	1.87	0+13.5	1.35	0+15.0	.25
8-6	2.22	0+13.5	1.23	0+15.0	.23
8-7	1.81	0+13.5	1.14	0+15.0	.20
8-8	1.71	0+04.5	1.54	0+3.0	3.10
8-11	1.79	0+04.5	1.23	0+3.0	2.12

Weighted Average = 1.18 feet per day.

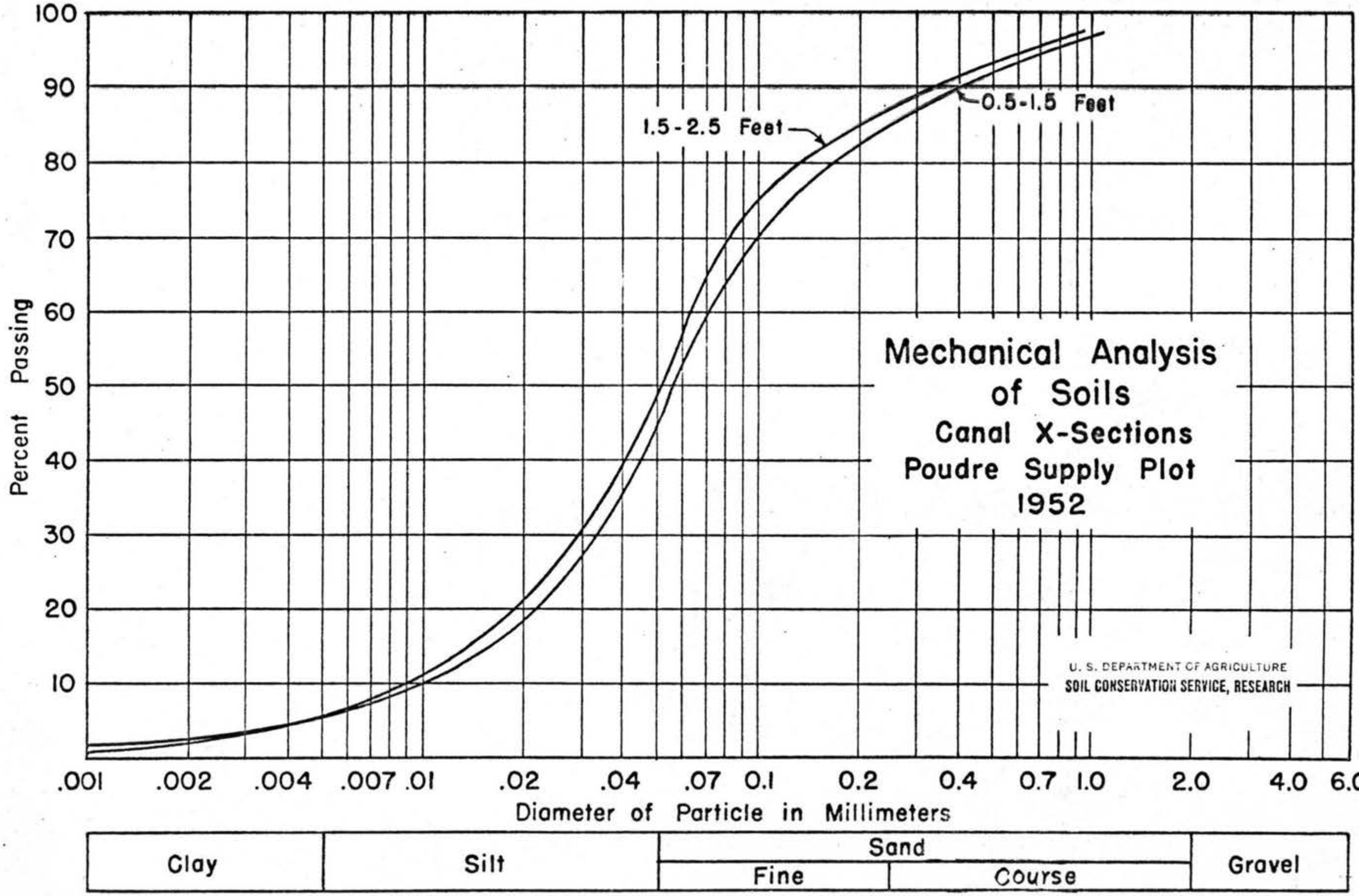

Mechanical Analysis of Soils
Canal X-Sections
Poudre Supply Plot
1952
1.5 - 2.5 Feet
0.5-1.5 Feet
Percent Passing
Percent Retained
Diameter of Particle in Millimeters
.001
.002
.004
.007
.01
.02
.04
.07
0.1
0.2
0.4
0.7
1.0
2.0
4.0
6.0
Clay
Silt
Sand
Fine
Course
Gravel
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, RESEARCH

Figure 28

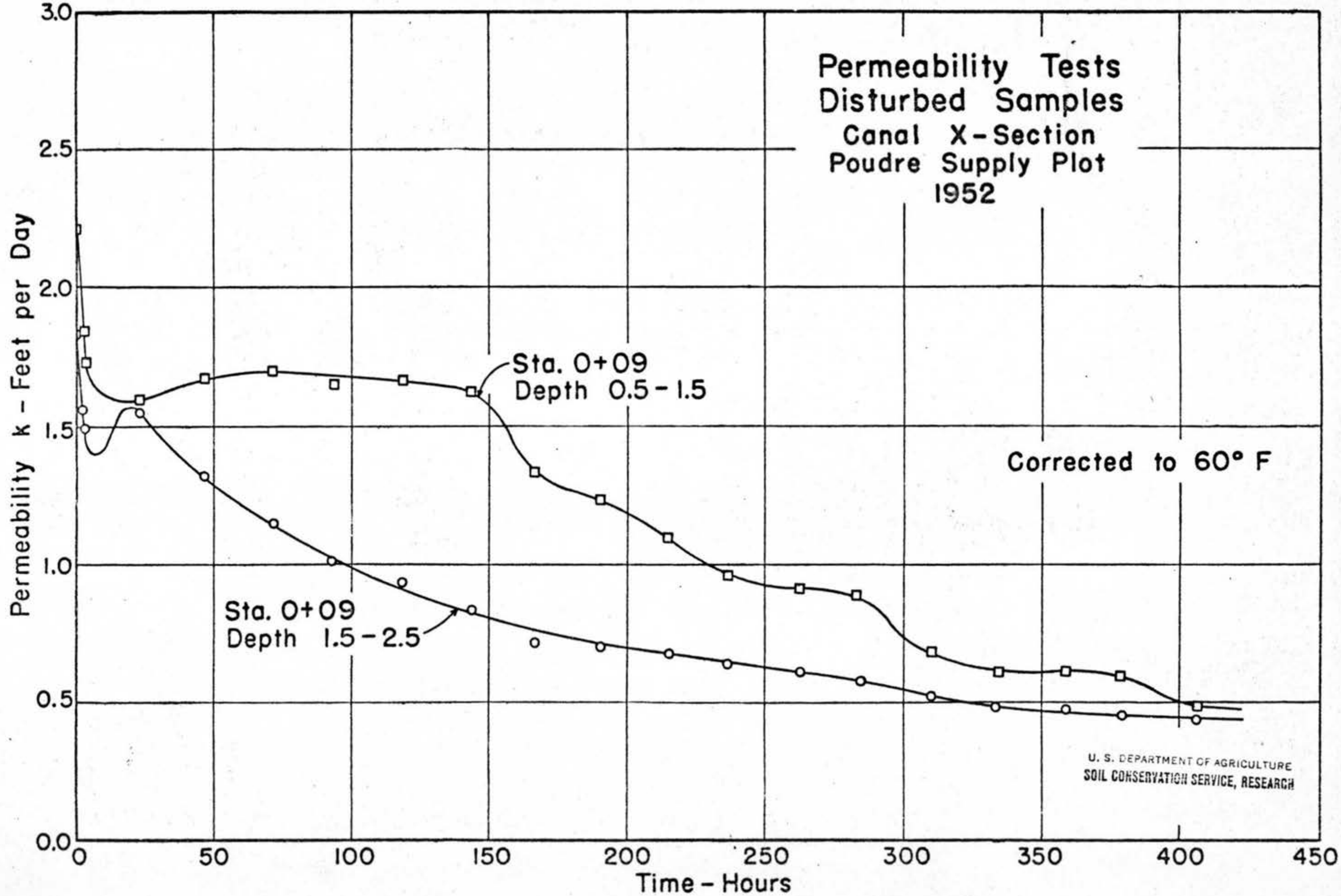

Permeability Tests
Disturbed Samples
Canal X-Section
Poudre Supply Plot
1952
Corrected to 60° F
Sta. 0+09
Depth 0.5-1.5
Sta. 0+09
Depth 1.5-2.5
Permeability k - Feet per Day
Time - Hours
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
50
100
150
200
250
300
350
400
450
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, RESEARCH

Figure 29

invert of the canal section. A plot of the results of these tests with the permeability corrected for viscosity to a standard temperature is shown in figure 30. High initial permeabilities in the neighborhood of 1.2 feet per day were obtained with the rates decreasing after 180 hours of operation to 0.17 foot per day.

The initial ponding tests in the section were made by letting a continuous flow of water enter the canal and cutting this flow off daily for a short period and noting the drop in water surface. For the second series of tests it was possible to use a water meter in the line so a continuous determination of seepage was possible. Figure 31 is a plot of the results of these tests. This shows a rate of over 3.5 feet per day at the beginning of the first series which decreased to 1.1 at the end of the period. Two days after the water was turned back into the section a lining of waste cement dust was placed in the canal. This lining had the effect of speeding up the seepage approximately 50 percent over the original rate.

The waste cement dust was obtained from the Ideal Cement Plant near La Porte, Colorado. Engineers from the Cement Company, in searching for some use for the waste product, suggested that the dust be used to check its suitability for stopping seepage. A chemical analysis of the dust showed it to have practically the same percentage of chemical ingredients as commercial cement except that there was a higher content of sulphur trioxide. The lining was placed by scattering the dust in the water and allowing it to

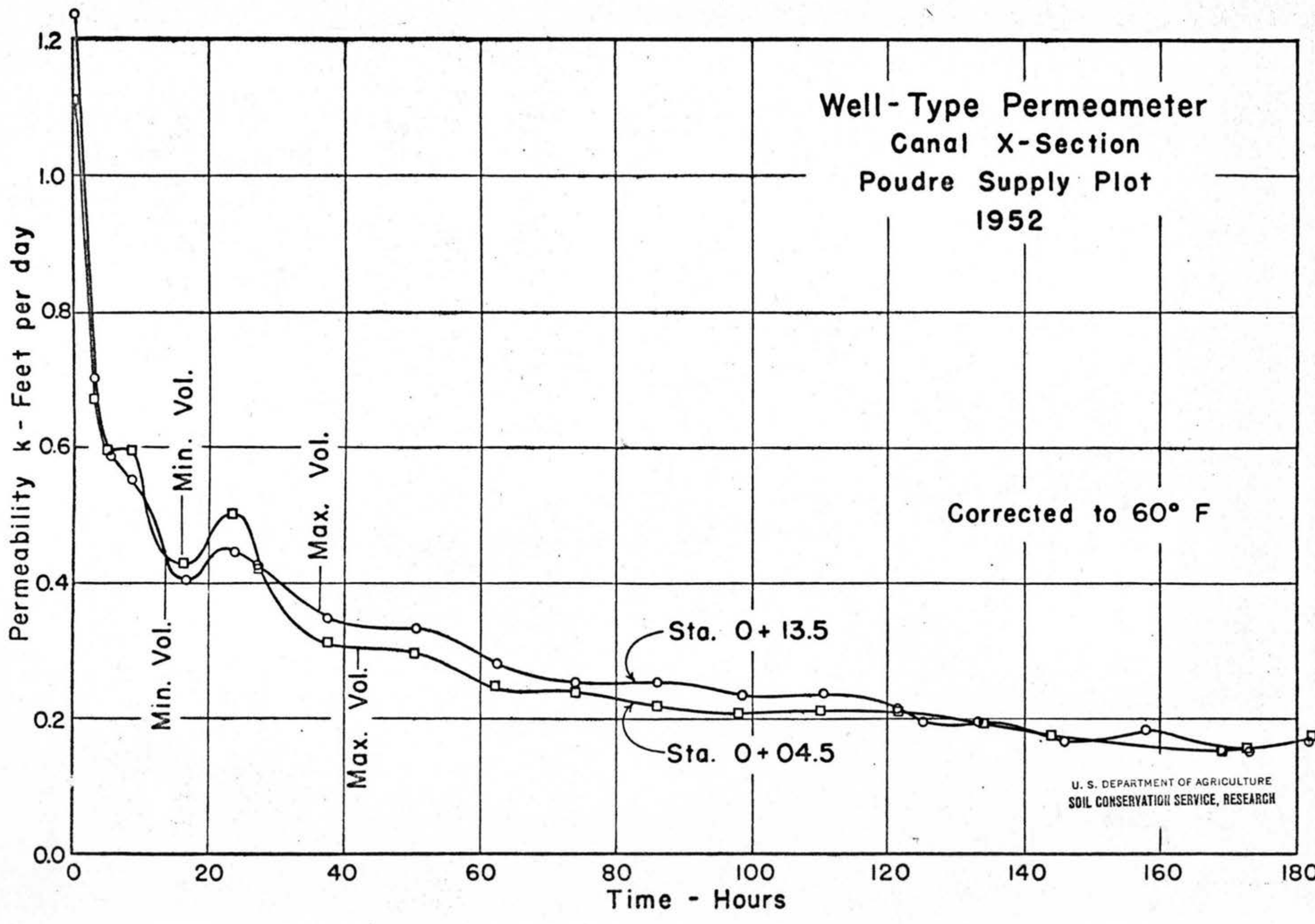

Well-Type Permeameter
Canal X-Section
Poudre Supply Plot
1952
Corrected to 60° F
Permeability k - Feet per day
Time - Hours
Min. Vol.
Max. Vol.
Sta. 0 + 13.5
Sta. 0 + 04.5
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, RESEARCH
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0
20
40
60
80
100
120
140
160
180

Figure 30

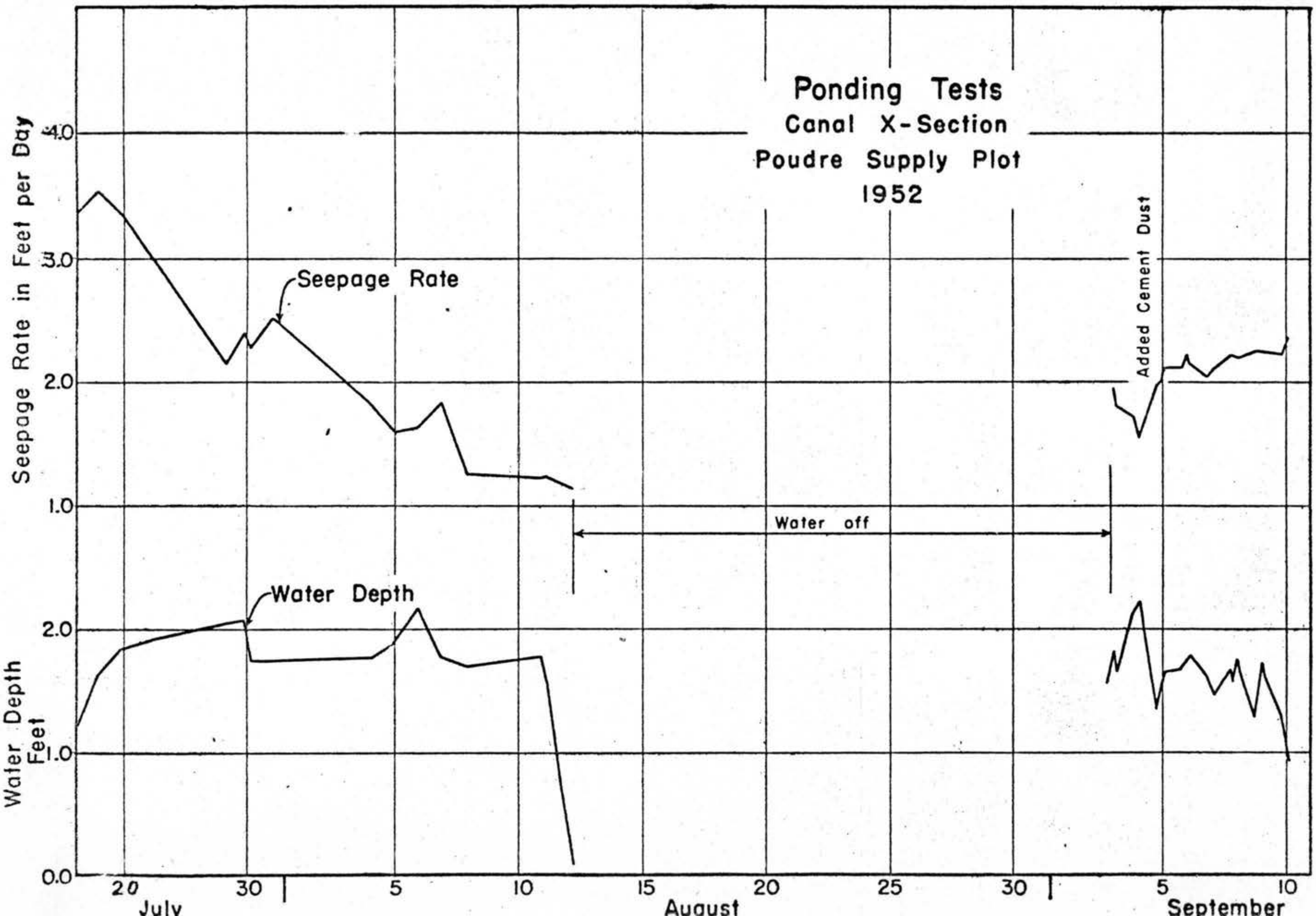

Ponding Tests
Canal X-Section
Poudre Supply Plot
1952
Seepage Rate in Feet per Day
4.0
3.0
2.0
1.0
Seepage Rate
Water Depth
Added Cement Dust
Water off
Water Depth Feet
2.0
1.0
0.0
20
30
5
10
15
20
25
30
5
10
July
August
September

Figure 31

settle on the sides and bottom of the canal. An amount of the dust was added which would approximate a one-inch lining.

Seepage meter tests with two types of meters were made in the section during the first ponding test. These meters were placed in four different locations along the bottom of the Canal. The results of these tests are tabulated in table 15. The variation in rates over the 18 foot section was over ten-fold. However, a weighted average of the four locations gave a rate of 1.18 feet per day as compared to 1.23 as determined from the ponding tests for the same period.

Poudre Supply Canal Seepage Tests

Ponding and seepage meter tests were made on a section of the Poudre Supply Canal between Stations 167+50 and 186+00 in 1951. Because of changes in grade when emerging from a lined into an unlined section and from the unlined back to the lined section, a natural pool was formed between these stations when the water was cut off. Well permeameter tests were made in 1952 to check the results previously obtained. Since it was desired to make the well permeameter tests in undisturbed material they were made along a line approximately 60 feet to the right of the canal center line outside of the embankment. Four permeameter tests were made in wells equally spaced along this line.

A complete soil analysis was made of samples taken at each permeameter location. The analyses are tabulated on tables 16, 17 and 18. The combined mechanical analysis (table 16) shows

Table 16.-- Combined Mechanical Analysis of Soils
Poudre Supply Canal
1952

Sample 1.5-2.5 Ft. Station	Colloids .001 mm Percent	Clay .001-.005 mm Percent	Silt .005-.05 mm Percent	Fine Sand .05-.25 mm Percent	Coarse Sand .25-2.0 mm Percent	Gravel 2.0 mm Percent	U. S. Bureau of Soils Classification
170+44	2.5	3.0	37.5	46.0	11.0	0.0	Sandy Loam
174+46	1.0	4.5	24.5	61.0	9.0	0.0	Sandy Loam
179+30	1.0	8.0	46.5	38.5	6.0	0.0	Loam
183+60	0.0	3.0	18.5	69.0	9.5	0.0	Sandy Loam

Table 17.-- Chemical Analysis of Soils
Poudre Supply Canal
1952

Sample Location	pH	Total Soluble Salts Percent	Total Gravimetric Salts Percent	Organic Material Percent	$Ca\ CO_3$ (Lime)* Percent
170+44	7.8	.10	0.5	1.3	0.6
174+46	7.7	.02	0.5	0.7	0.2
179+30	8.1	.08	0.5	1.1	5.6
183+60	8.3	.02	0.5	0.9	1.0

Table 18.-- Soil Analysis
Poudre Supply Canal
1952

Sample	Liquid Limit	Plastic Limit	Plasticity Index	Atterburg Classification Index	Bureau of Soils Classification	K Disturbed Sample	K Well-perm. Test
Station						Ft/day	Ft/day
170+44	31.2	17.7	13.5	Medium Plastic	Sandy Loam	.87	.49
174+46	22.9	20.3	2.6	Feebly Plastic	Sandy Loam	1.65	.47
179+30	33.2	18.9	14.3	Medium Plastic	Loam	.55	.42
183+60	22.3	20.9	1.4	Feebly Plastic	Sandy Loam	.55	.58

the size distribution of the samples which is also plotted in figure 32. The samples were all classified as sandy loam except at Station 179+30 where the silt content was higher and was classified as a loam.

The chemical analysis (table 17) shows that all samples were moderately alkaline in reaction. None of the samples contain an appreciable amount of gypsum and the total soluble salt content is low. The sample at Station 179+30 had a fairly high lime content. Table 18 shows the Atterburg limits of the soil samples. These limits give a classification of medium plastic for the samples from Stations 170+44 and 183+60. At the remaining stations a feebly plastic soil is indicated.

Permeability tests of disturbed samples are shown in figures 33 and 34. These plots show that the samples gave quite different results throughout the test period. The end determinations of the samples, shown in table 18, gave permeabilities of 0.87 foot per day for Station 170+44, 1.65 at Station 174+46 and 0.55 at Stations 179+30 and 183+60.

The well permeameter tests were made using the procedure previously discussed except that the depths were approximately two feet, consequently the bottom of the hole did not correspond to the elevation of the invert of the canal. The results of these tests are shown in figures 35 and 36, and the end determinations are tabulated in table 18. The values range from .42 to .58 foot per day as compared to .55 to 1.65 for the disturbed sample determinations.

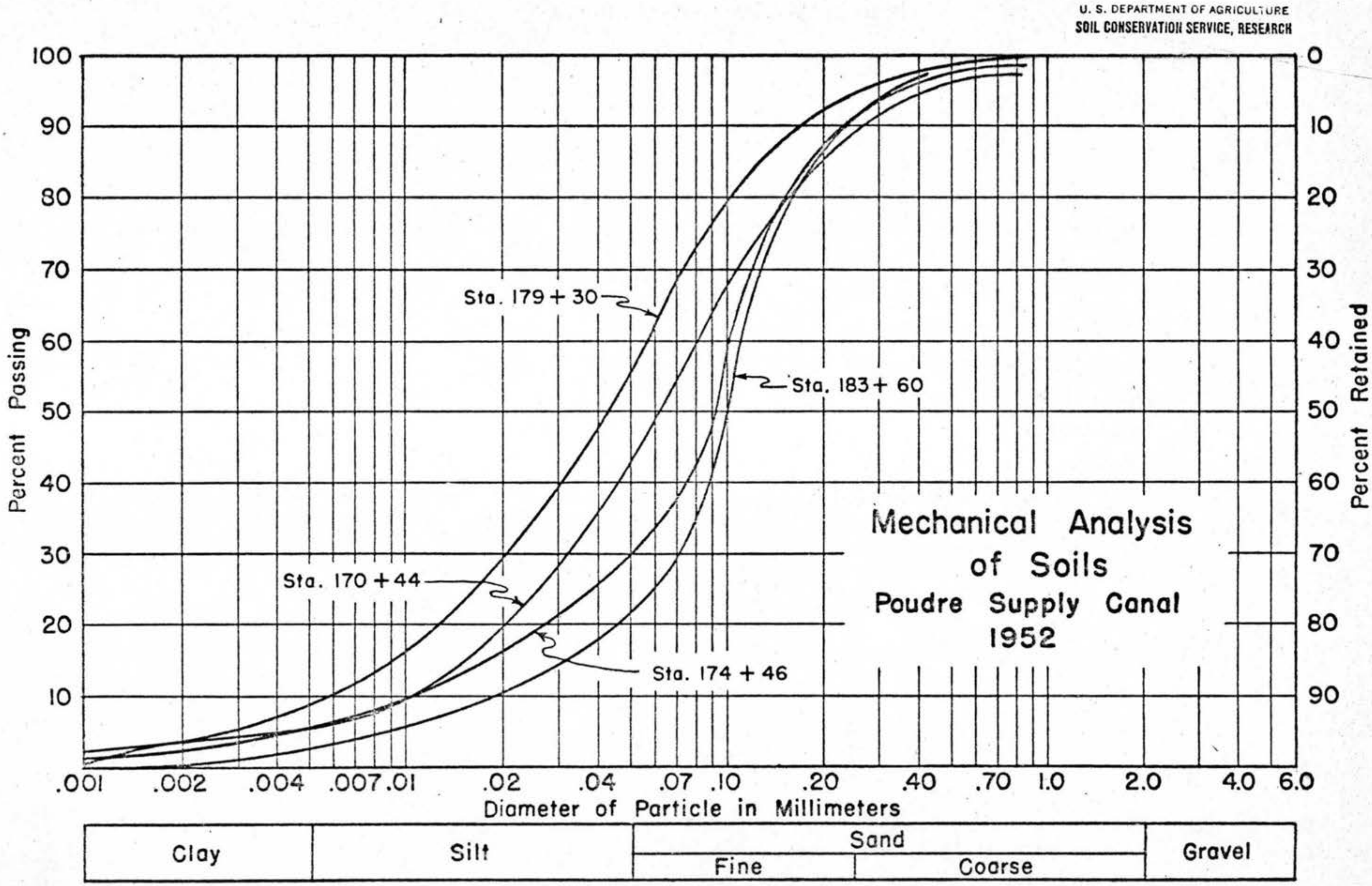
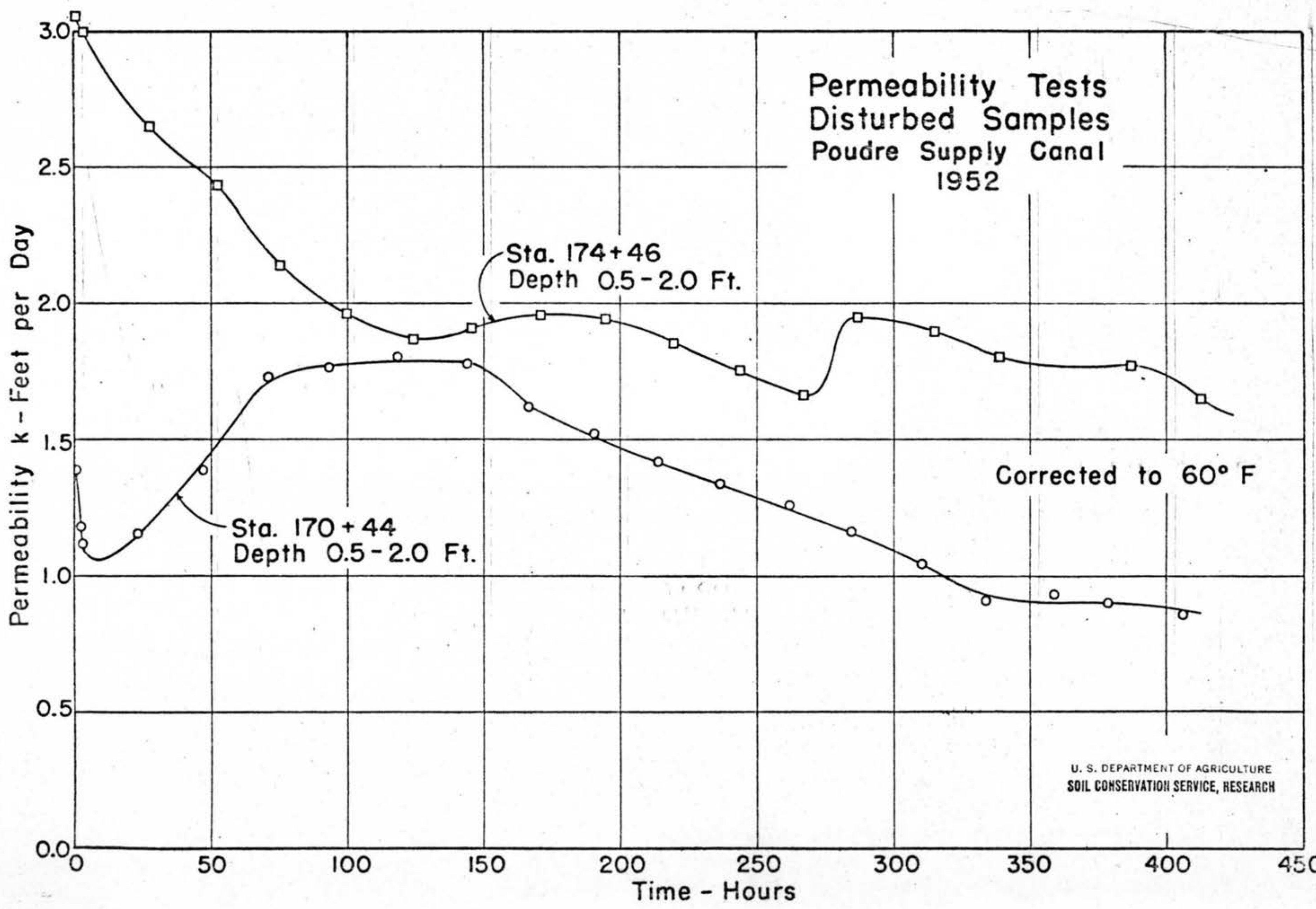

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, RESEARCH
Mechanical Analysis
of Soils
Poudre Supply Canal
1952
Sta. 179 + 30
Sta. 183 + 60
Sta. 170 + 44
Sta. 174 + 46
Percent Passing
Percent Retained
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
80
90
.001
.002
.004
.007
.01
.02
.04
.07
.10
.20
.40
.70
1.0
2.0
4.0
6.0
Diameter of Particle in Millimeters
Clay
Silt
Sand
Fine
Coarse
Gravel

Figure 32



Permeability Tests
Disturbed Samples
Poudre Supply Canal
1952
Sta. 174+46
Depth 0.5-2.0 Ft.
Sta. 170+44
Depth 0.5-2.0 Ft.
Corrected to 60° F
Permeability k - Feet per Day
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
50
100
150
200
250
300
350
400
450
Time - Hours
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, RESEARCH

Figure 33

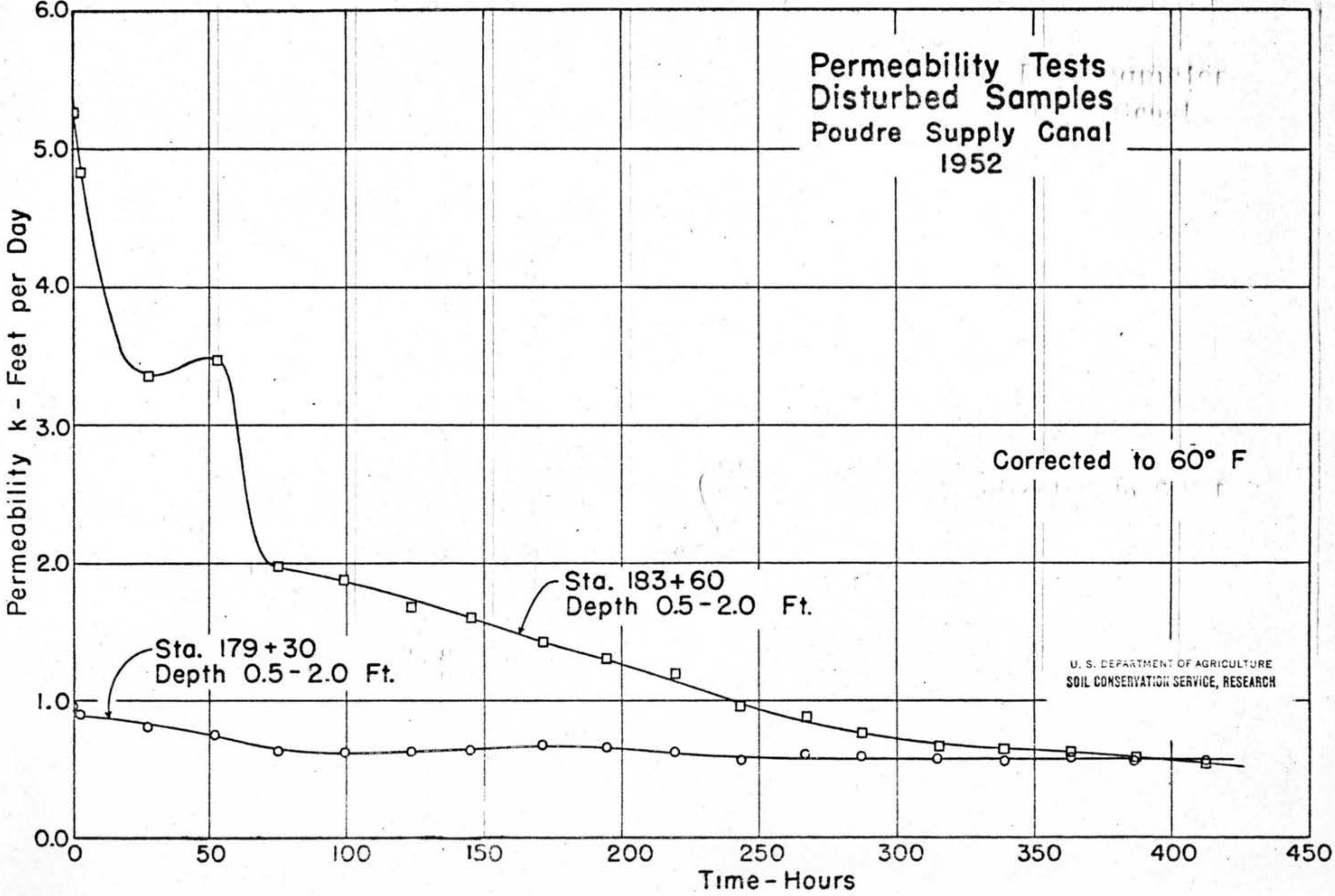

Permeability Tests
Disturbed Samples
Poudre Supply Canal
1952
Corrected to 60° F
Sta. 183+60
Depth 0.5-2.0 Ft.
Sta. 179+30
Depth 0.5-2.0 Ft.
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, RESEARCH
Permeability k - Feet per Day
Time-Hours
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
50
100
150
200
250
300
350
400
450

Figure 34

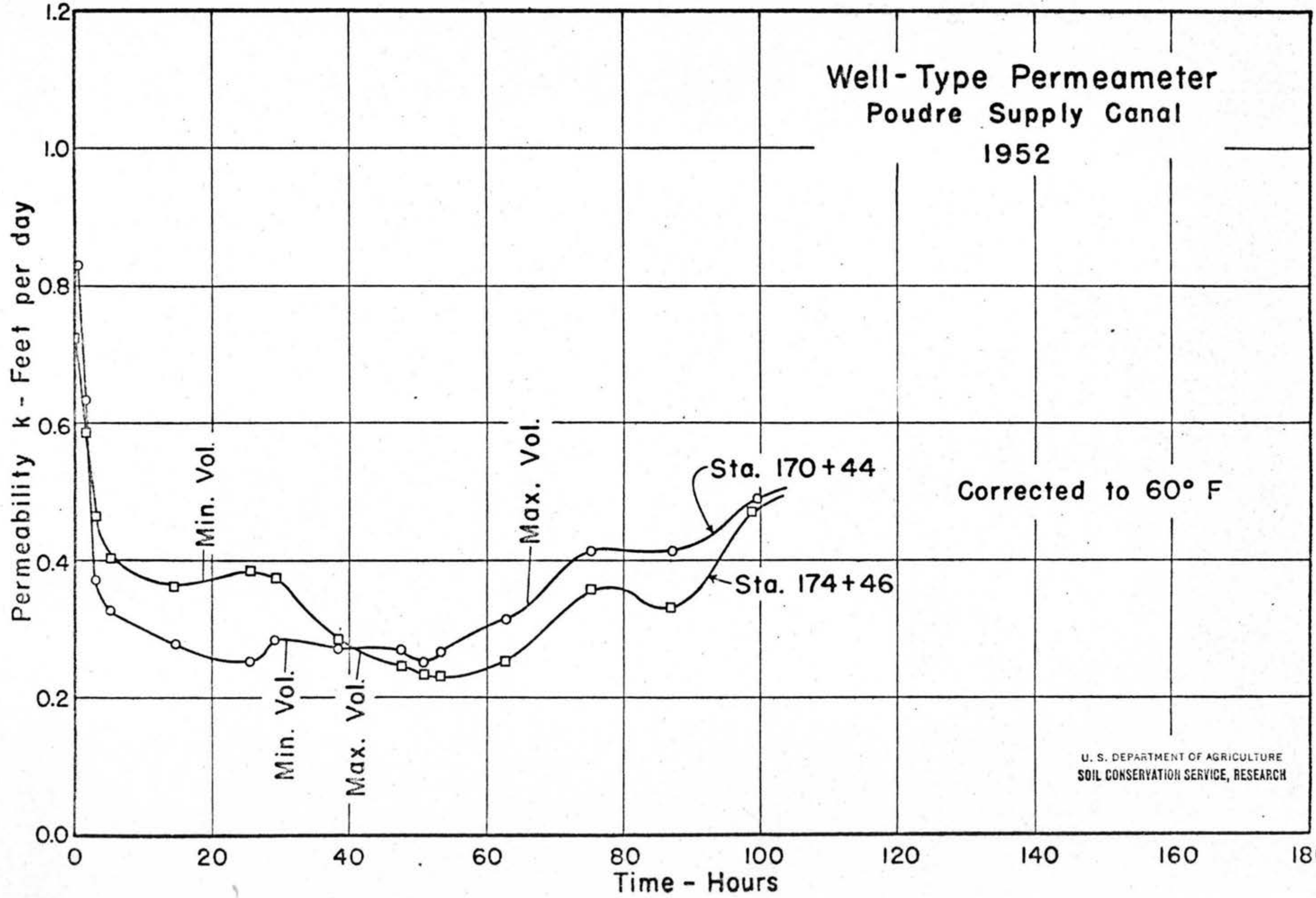

Well-Type Permeameter
Poudre Supply Canal
1952
Corrected to 60° F
Sta. 170+44
Sta. 174+46
Min. Vol.
Max. Vol.
Min. Vol.
Max. Vol.
Permeability k - Feet per day
Time - Hours
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
20
40
60
80
100
120
140
160
180
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, RESEARCH

Figure 35

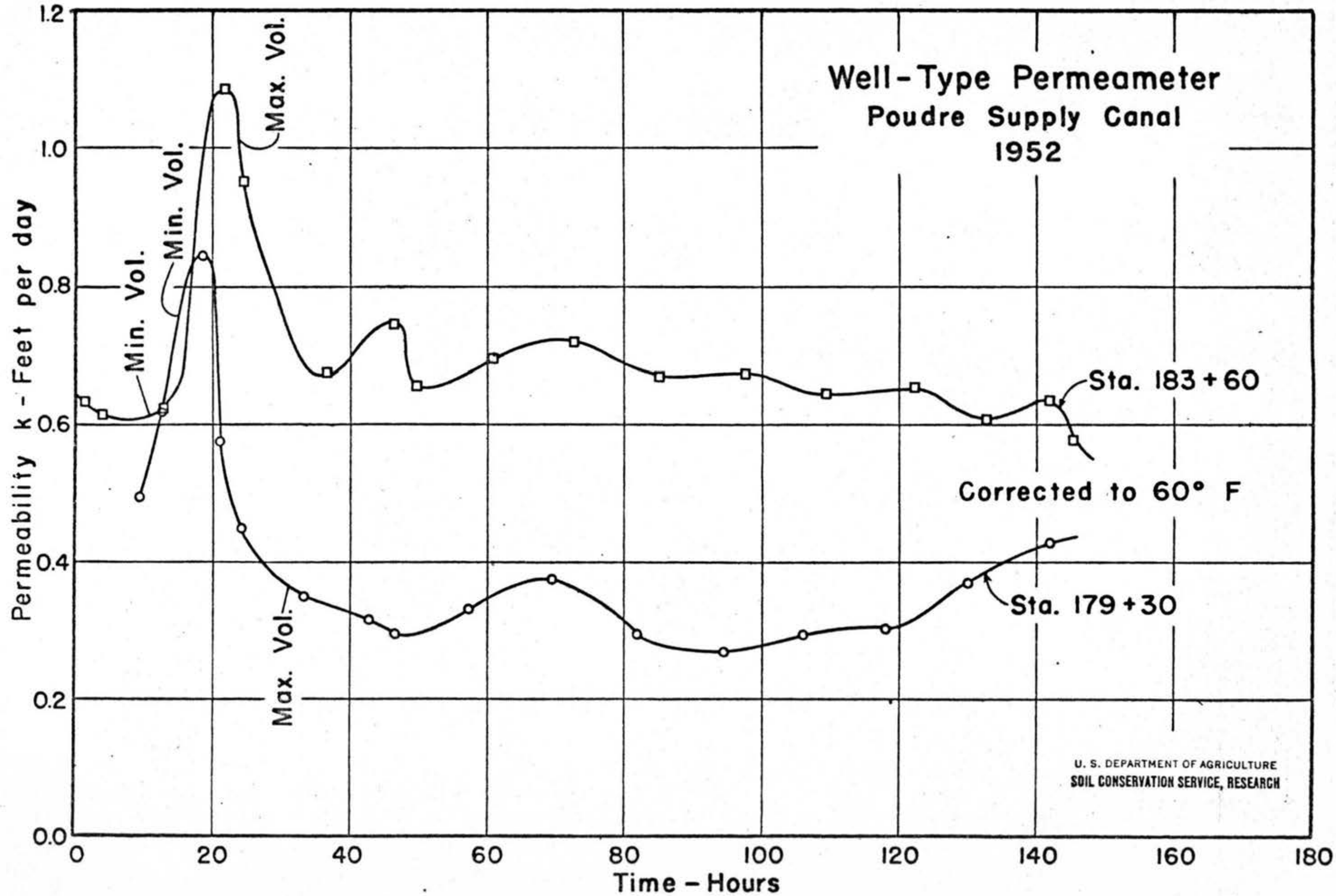

Well-Type Permeameter
Poudre Supply Canal
1952
Permeability k - Feet per day
Time - Hours
Min. Vol.
Min. Vol.
Max. Vol.
Max. Vol.
Sta. 183+60
Sta. 179+30
Corrected to 60° F
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, RESEARCH

Figure 36

After the water in the canal was shut off for the season it was again possible to make ponding tests in the section. For this purpose a staff gage was mounted at each end of the section and readings were made twice daily. The results of these tests are tabulated in table 19. The seepage ranged from 0.137 to 0.226 foot per day which compares closely with the first ponding test for the previous season as shown in the Progress Report for 1951 (8). The permeability K was computed by using the formula proposed by Muskat (5).

$$K = \frac{Q}{l(B+2h)}$$

where: K = permeability
Q = discharge in cubic feet per unit of time
l = length of section
B = width of water surface
h = depth of water

Using this formula and correcting the effects of viscosity to a standard temperature gave permeability values ranging from 0.131 to 0.226 foot per day. These values are also tabulated in table 19. The well permeameter tests indicated rates of from 0.42 to .58 foot.

Table 19.-- Pool Measurements of Canal Seepage
Poudre Supply Canal - Stations 167+50 to 186+00
1952

Date	Time	Depth Water	Average Wetted Perimeter	Average Width	Drop for Period	Evap. for Period	Corrected Drop	Length of Period	Drop	Seepage	Perm. K at 60° F
1952		Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Days	Ft/day	Ft/day	Ft/day
10-18	4:40P	1.710	--	--	--	--	--	--	--	--	--
10-19	8:40A	1.610	38.0	37.0	0.100	0.005	0.095	0.667	0.142	0.166	0.158
10-19	3:55P	1.550	37.7	36.8	.060	.003	.057	.302	.189	.226	.214
10-20	8:40A	1.440	37.4	36.5	.110	.004	.106	.698	.152	.179	.169
10-20	4:45P	1.390	37.1	36.3	.050	.004	.046	.337	.137	.162	.153
10-21	8:40A	1.295	36.9	36.1	.095	.001	.094	.663	.142	.169	.161
10-21	4:45P	1.230	36.6	35.8	.065	.006	.059	.344	.171	.198	.190
10-22	8:55A	1.145	36.3	35.6	.085	.006	.079	.667	.118	.137	.131
10-22	4:10P	1.088	36.1	35.4	.057	.005	.052	.302	.172	.202	.194
10-23	9:05A	1.000	35.8	35.2	.088	.005	.083	.705	.118	.134	.128
10-23	4:45P	0.930	35.5	34.9	.070	.005	.065	.319	.204	.234	.226

DISCUSSION OF RESULTS

Seepage Rings

As in previous seasons of seepage ring operation the effect of time with its related factors was noted as being important in the seepage determinations. At the Bellvue rings there was a gradual decrease in seepage rates throughout the season. Part, but not all of this decrease, could be attributed to the fact that silt was brought in with the water on several occasions. This silt layer was broken up by raking on two occasions which had the effect of temporarily speeding up the seepage rate. At the Poudre Supply Plot rings the seepage rate at the end of four months of operation was practically the same as the initial rate. After an initial period of decreasing rates there was a marked increase in seepage for quite a long period. After a series of tests to determine the effect of water depth on the seepage rates there was a major increase in seepage. Two factors probably contributed to this phenomenon: the fact that the soil had been disturbed and the fact that soluble material was being leached from the soil throughout the test period.

As in previous tests, it was again observed that the rate of seepage was not directly proportional to the depth of water but to the depth plus some length of soil column. In previous reports (7), (8), a method of determining the permeability by projecting the rate vs depth curve until zero depth was reached was doveloped. The rate at zero depth should equal the permeability since the hydraulic gradient would equal unity at this point. A formula developed by Glover (4), applicable to the seepage rings, was used to check the results. It was found that with a constant rate-depth relationship, a variable value of K was obtained for various depths using the Glover formula. This difference was attributed to the fact that in the Glover formula, the length of the path of percolation was taken as the embedded length of the cylinder plus a constant times the diameter. The constant was determined by electrical analogy methods. However, a length of percolation determined by using the effect of depth tests and projecting the rate-depth relationship until a zero rate was reached gave constant values of permeability when used in the Glover formula.

The effect of temperature tests which were made at both seepage rings and the ring for study of effect of ground water fluctuation gave results which were contrary to the accepted ideas as to the effect of temperature.

After the seepage rates were corrected for changes in viscosity with temperature they showed a greater variation with temperature than before. Because of this fact the effect of changes in porosity due to the expansion and contraction of the air bubbles in the soil as the vapor pressure changed with temperature, was investigated. In order to investigate this effect, the percentage of air remaining in the soil had to be assumed. The computations indicated that making the correction for somewhere between 5 and

10 percent of air resulted in a corrected seepage rate, that is practically identical with the originally observed seepage. In other words the viscosity and porosity corrections are compensating. The fact that differences in temperature under certain conditions do not affect the rate of percolation has been observed in experiments elsewhere (6). This is a complex problem and additional study will have to be given to it.

Piezometer measurements at each seepage ring location showed that the water table was not affected by the operation of the seepage rings. In each case this was probably due to the fact that there was not an impermeable boundary near the rings. At the Poudre Supply rings the presence of ground water was not apparent throughout the season. The water at the Bellvue rings fluctuated with the stage of the Poudre River nearby.

One purpose of the present study is to determine the accuracy of seepage meters and how to install them to get the best results. Over the four seasons of testing the SCS meter has been used in various types of soil contained in the seepage rings. The plastic bag (USBR) meter has been used for two seasons and generally was installed side by side with the SCS meter. The meters were usually left in place for two-week periods. In all cases the meters were installed by pushing or jacking and never by hammering. In two types of soil, clay loam and sand, it was found that immediately after the meters were placed very high rates were determined. However, after several days the rates decreased and fairly constant seepage rates were determined.

On one occasion the measuring devices on the seepage meters were switched to see if the method might affect the results. Determinations were made with the plastic bag on one meter and the cup on the other. Another determination was immediately made with the plastic bag and the cup interchanged. This procedure was followed at the two seepage ring installations. The results of these tests showed no significant difference in the rates, indicating that the method was not a factor in the determination. In the study made at the University of Idaho (11) it was thought that the plastic bag meter gave erroneous results because of the bag not transmitting the pressure equally from the outside to the inside of the bag.

In an effort to develop a calibration curve for the seepage meter, figure 37 was prepared. The data for this plot were taken from almost 300 individual seepage meter determinations in the seepage rings. Only those determinations taken after the meter had been in place at least two days were used. This plot shows that for seepage meter rates from 0.1 to 1.0 foot per day the meter generally shows rates less than the seepage rings. For rates greater than 1.0 the seepage meter gave rates which were higher than those shown for the seepage ring. At the University of Idaho study (11) the seepage meter gave rates lower than from the seepage tank over a range of 0.2 to 2.00 feet per day.

It is generally known that as the ground water approaches the ground surface the seepage rate will decrease. The magnitude

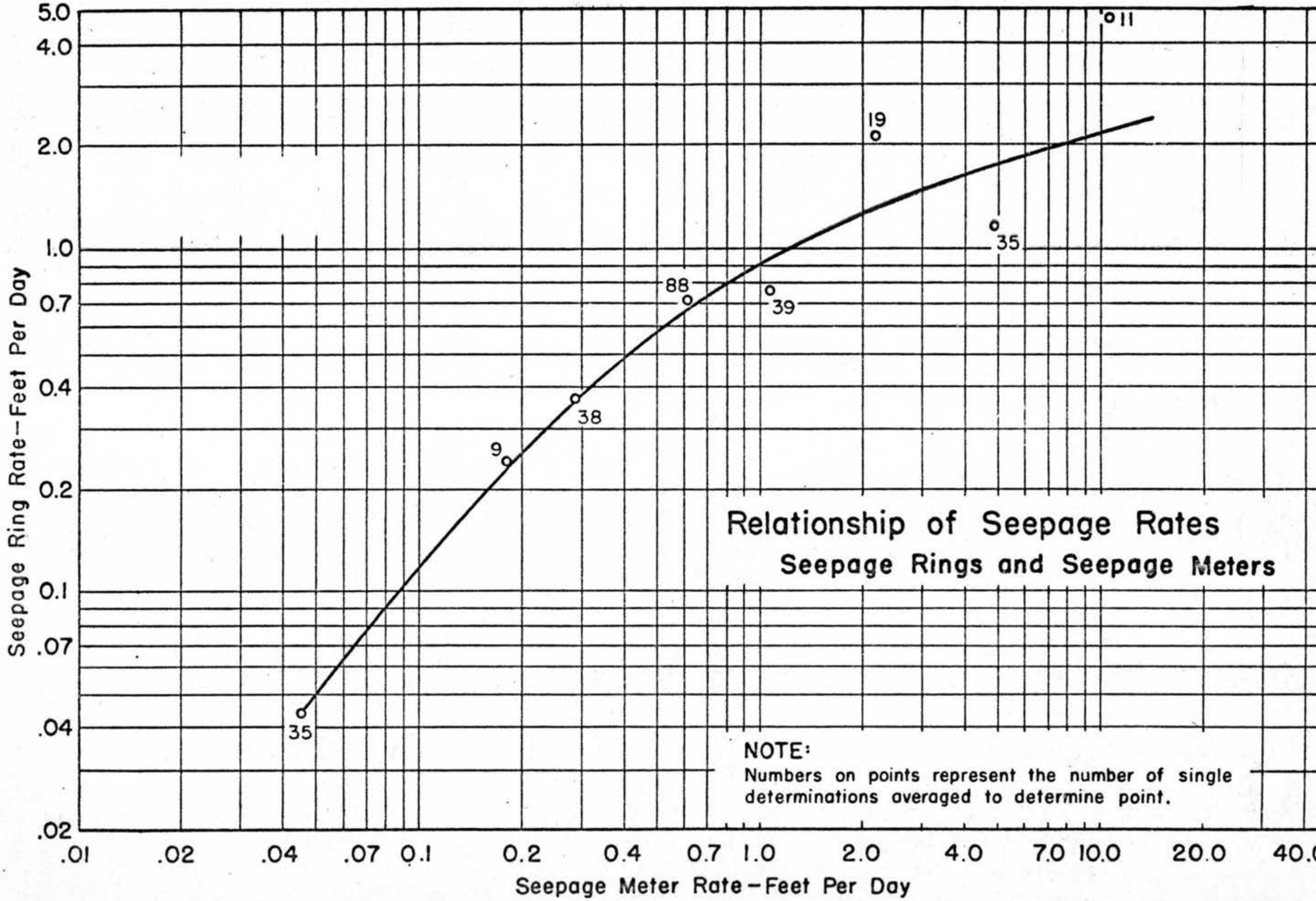

Relationship of Seepage Rates
Seepage Rings and Seepage Meters
NOTE:
Numbers on points represent the number of single determinations averaged to determine point.
Seepage Ring Rate – Feet Per Day
Seepage Meter Rate – Feet Per Day
5.0
4.0
2.0
1.0
0.7
0.4
0.2
0.1
.07
.04
.02
.01
.02
.04
.07
0.1
0.2
0.4
0.7
1.0
2.0
4.0
7.0
10.0
20.0
40.0
11
19
35
88
39
38
9
35

Figure 37

of this decrease is not known. Equipment was constructed so that the ground water could be controlled to study this effect. Difficulty was encountered in separating the effects of the ground water fluctuation and other factors which affect the seepage rates. It was noted that the rates increased or decreased as the ground water was lowered or raised. Further study of this problem is planned for the next season.

Well permeameter tests which were conducted at two locations gave results which did not compare favorably with results as determined from ponding tests. Generally, it has been found that the well-permeameter tests give results which are much higher than those for the ponding tests. The following table is a summary of results of permeability tests in 1952.

Station	K Ponding Ft/day	K Well Perm. at Min. Vol. Ft/day	K Well Perm. at end of Test Ft/day	K Disturbed Sample Ft/day
		Canal X-Section		
0+04.5	.90*	.43	.16	.46
0+09.0	-	.44	.16	-
		Poudre Supply Canal		
170+44	0.15*	.29	.49	.87
174+46	-	.37	.47	1.65
179+30	-	.76	.42	.55
183+60	-	.61	.58	.55
Average	.15	.51	.49	.90

*Average for canal

In the case of the Canal X-Section the well permeameter test results are lower than those for the ponding tests. The disturbed sample determination is also lower than the ponding tests. For the Poudre Supply Canal tests the well-permeameter and disturbed permeability tests gave higher results than those from ponding. The soil types in these two locations are very similar. The chemical compositions are very nearly the same with the exception that the soil at the Canal X-Section contains a higher percentage of lime.

Seepage meter tests made in the Canal X-Section were in very close agreement with the results of ponding tests. Here the seepage meters gave a seepage rate of 1.18 feet per day as compared to 1.23 for the ponding test.

The addition of a waste cement dust lining to the canal section had the effect of speeding up the seepage rate about 50 percent. It is possible that there was a base exchange of the material which caused this to happen. The cement dust might be effective in a material which contains a considerable amount of sand.

SUMMARY

As in previous seasons of seepage ring operation the effect of time with its related factors was noted as being important in the seepage determinations. Without the additional factor of silting it was found that the seepage rate generally decreased with time but in one case the rate continued to increase during the testing season.

The "Effect of Depth Tests" showed that the seepage rate was not directly proportional to the depth of water in the rings. The rate was proportional to the depth plus some length of soil column. This length varied with the location and type of soil.

The tests conducted to determine the effect of temperature showed that the seepage rate was not constant even after the rings had been in continuous operation for several months. A variation of approximately 20 percent in rates over a 48 hour period was observed at one location with the variation becoming more pronounced after correcting the data for the change in viscosity. An attempt was also made to correct the data for changes in porosity as the volume of air bubbles in the soil changed with vapor pressure. It was observed that the corrections for viscosity and those for changes in vapor pressure were compensating.

At each seepage ring location measurements of the elevation of the ground water with piezometers showed no change in the position of the water table which could be attributed to seepage ring operation.

A calibration curve for the seepage meters is presented which shows that for measured rates up to 1.0 foot per day the seepage meters generally measured less than the true seepage rate. For rates of more than 1.0 the seepage meters gave results which were too high.

By switching the measuring devices on the seepage meters it was determined that the method had no effect on the results of the seepage meter measurements. The rates shown by the SCS and USBR seepage meters were usually in close agreement when they were installed side by side.

It was observed, using the equipment for study of the effect of water table elevation, that as the ground water approached the ground surface there was a decrease in seepage rate. The exact relationship of the depth to ground water and the seepage rate was not determined because of uncertainties in the data.

The studies to determine the relationship of the well permeameter tests to the ponding tests in two canals gave contradictory results. At one location the well permeameter tests gave a permeability which was one-half that determined from the ponding tests while at the other location the well permeameter gave results which were three times those from the ponding tests. Seepage meter tests in one of the canal sections gave results which were very near those for ponding tests.

PROGRAM FOR 1953

During the study of seepage it has become apparent that the capillary tension in the soil may be a factor in seepage, even after the soil has been wet for some time. The capillary tension in saturated soil should be zero, but if the soil is not saturated, there may be a definite tension which sould affect the seepage rate. The present plan is to install tensiometers in the soil in the seepage rings to find out what the capillary tension is. Capillary tension may also be a factor in well permeameter observations, particularly when readings are taken for only a few hours. This also will be investigated.

The study of the effect of elevation of ground water on the seepage, which was started in 1952, will be continued and expanded. The observations made in 1952 were on sandy loam. Because of the difficulties encountered on account of leaks that developed, the observations on the sandy loam will be carried on for another season. In addition the seepage rings in sand at the Bellvue Laboratory site will be modified so that the effect of the depth to ground water in sand may also be studied. Both sets of rings will be operated under the same conditions.

Well permeameter tests were made along the center line of a section of the proposed North Poudre Supply Canal in 1951, in cooperation with the Soils Division of the Bureau of Reclamation. Estimates of seepage, based on the permeameter readings, were made by the Soils Division. The canal is now completed and water will be delivered through it in the summer of 1953. The present plan is to construct dams in the canal after the irrigation season, in order to check the estimates of seepage previously made. The sections between the dams will be filled with water and the seepage rate will be determined by noting the drop in the water surface of the ponds. The seepage rates determined by the two methods will be compared.

Studies of the effect of temperature on the seepage rate indicate that the corrections due to changes in viscosity and porosity with temperature are compensating. The principles involved have not been determined and in order to study this problem laboratory studies are planned. Permeameter tests will be made with water at different temperatures to see whether the permeability changes with temperature. Soils of different types will be tested.

After the field work on the project during 1952 is completed the final report on the seepage study will be prepared.

LITERATURE CITED

(1) Allison, L. F.
1947. EFFECT OF MICROORGANISMS ON PERMEABILITY OF SOILS UNDER PROLONGED SUBMERGENCE. Soil Science Vol. 63, 439-449.

(2) Christiansen, J. E.
1944. EFFECT OF ENTRAPPED AIR ON PERMEABILITY OF SOILS. Soil Science Vol. 58, 355-365.

(3) Franzini, J. B.
1951. POROSITY FACTOR FOR CASE OF LAMINAR FLOW THROUGH GRANULAR MEDIA. Transactions, American Geophysical Union Vol. 32, 443-446.

(4) Glover, R. E.
1949. POSSIBLE METHODS FOR RAPID DETERMINATION OF SOIL PERMEABILITIES. Memorandum to R. F. Blanks, 4 p.

(5) Muskat, M.
1937. THE FLOW OF HOMOGENEOUS FLUIDS THROUGH POROUS MEDIA. McGraw-Hill Book Co., New York, New York, 763 p.

(6) Pillsbury, A. F.
1950. EFFECT OF PARTICLE SIZE AND TEMPERATURE ON THE PERMEABILITY OF SAND TO WATER. Soil Science Vol. 70, 299-300.

(7) Robinson, A. R. and Rohwer, Carl
1951. PROGRESS REPORT ON THE STUDY OF SEEPAGE LOSSES FROM IRRIGATION CHANNELS. USDA, Division of Irrigation, Colorado A and M College, Fort Collins, Colorado, 36 p.

(8) Robinson, A. R. and Rohwer, Carl
1952. PROGRESS REPORT ON THE STUDY OF SEEPAGE LOSSES FROM IRRIGATION CHANNELS. USDA, Division of Irrigation, Colorado A and M College, Fort Collins, Colorado, 36 p.

(9) Rohwer, Carl
1950. PROGRESS REPORT ON THE STUDY OF SEEPAGE LOSSES FROM IRRIGATION CHANNELS, USDA, Division of Irrigation, Colorado A and M College, Fort Collins, Colorado, 17 p.

(10) Rollins, Ralph
1950. REPORT ON SOILS, HORTICULTURE PLOT SEEPAGE EXPERIMENT. Progress Report, Civil Engineering Section, Colorado A and M College, Fort Collins, Colorado, 35 p.

(11) Warnick, C. C.
1951. METHODS OF MEASURING SEEPAGE LOSSES IN IRRIGATION CANALS. University of Idaho, Moscow, Idaho, Engineering Experiment Station, Bulletin No. 8, 42 p.

(12) U. S. Bureau of Reclamation
1951. TENTATIVE INSTRUCTIONS FOR CONDUCTING WELL PERMEAMETER TESTS FOR THE ESTIMATION OF SEEPAGE FROM CANALS. U. S. Bureau of Reclamation, Earth Manual, 255-266.