U. S. DEPARTMENT OF AGRICULTURE

SOIL CONSERVATION SERVICE

R. M. Salter, Chief

Progress Report

STUDY OF SEEPAGE LOSSES FROM IRRIGATION CHANNELS

1951

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 WaterConservation
in cooperation with the
Colorado Agricultural Experiment Station
and the
U. S. Bureau of Reclamation

Fort Collins, Colorado
April 25, 1952

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pared under the direction of George D. Clyde, Chief, Division of
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PROGRESS REPORT
STUDY OF SEEPAGE FROM IRRIGATION CHANNELS
1951

* * * * * * *

by
A. R. Robinson and Carl Rohwer

INTRODUCTION

Early in 1949, the Bureau of Reclamation requested the Division of Irrigation Engineering, Soil Conservation Service, in cooperation with the Colorado Agricultural Experiment Station to make studies of seepage from irrigation canals as one phase of the Lower Cost Canal Lining Program set up by the Bureau. A memorandum of understanding, Asc-875, signed by the cooperating agencies became effective June 20, 1949, and has been renewed annually. The actual field work for the project started during the summer of 1949 and has continued each year 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. The plan for conducting the study is based on the construction of seepage rings in different types of soils, from which the seepage rate could be accurately determined and from which a study of the various factors influencing seepage would be possible. The seepage rate from these rings would be used as a standard for determining the accuracy of permeameters and seepage meters in measuring seepage. These field permeameters and seepage meters would be installed either within the rings or in the same general vicinity. Complete soil analyses including laboratory permeameter measurements would be made. Where possible, actual use of the field equipment on existing or proposed canals as a means of further improving or calibrating the equipment was planned.

During the first two years the seepage rings were installed in clay loam on the Horticulture Plot near Colorado A and M College and in sandy loam at the Bellvue Laboratory. Numerous measurements were made with the SCS type seepage meter and the well-type permeameter. In addition, weekly observations of the elevation of the ground water were made. Inflow-outflow as well as ponding measurements were made on the Arthur Ditch. Well-type permeameter tests were conducted along a section of the Poudre Supply Canal which is a part of the Colorado-Big Thompson project. Complete soil and water analyses were made at each test location.

During the 1951 season the seepage rings were again operated at the Bellvue Laboratory and a new seepage ring installation was made in clay soil near the Poudre Supply Canal, which was also operated for the season. In addition to the SCS type seepage meters which had been used the previous seasons, two USBR plastic bag type meters were tested. A plastic SCS type meter was constructed and used for seepage determinations. Three well-type permeameters were constructed and used for making permeability measurements. A section of the Poudre Supply Canal was checked for seepage by using the seepage meters and by ponding. Inflow-outflow measurements were again made on the Arthur Ditch. Assistance was given in making a series of well-type permeameter tests along the center line of an unlined section of the proposed North Poudre Supply Canal.

ACKNOWLEDGMENTS

The authors of this report wish to acknowledge the assistance of Messrs. Floyd Roush, Dale Lancaster, John Maletic and Chester A. Jones of the Bureau of Reclamation and Dr. Dean F. Peterson of Colorado Agricultural Experiment Station in conducting the study and interpreting the results. Laboratory tests of the physical and chemical characteristics of the soils were made by Mr. Paul D. Uerling, senior Civil Engineering student at Colorado A and M College and Mr. Robert C. Accola, Soil Scientist, Soil Conservation Service. Mr. Lowell Martin assisted on the field work of the project. The drawings for the report were prepared by Mr. James A. Willis, senior Civil Engineering student at Colorado A and M College. The report was typed by Miss Lois D. Blehm. Their assistance also, is gratefully acknowledged.

The site for the study of seepage at the Bellvue Laboratory was provided by the Jackson Ditch Company and the site on the Poudre Supply Canal by the Bureau of Reclamation. Peter Kiewit and Sons, Contractor on the Colorado-Big Thompson Project, leveled the site on the Poudre Supply Canal. Their cooperation on the study is greatly appreciated.

EQUIPMENT AND PROCEDURE

Seepage Rings

As explained in the progress reports submitted in 1950 (8) and 1951 (7), two concentric rings, one 6 feet and the other 18 feet in diameter were used in the experiments. (See figure 1). The annular space around the center pool acted as a buffer so that the seepage from the center pool would be unaffected by the boundary conditions. The rings were made of 16-gage galvanized sheet metal 36 inches wide. They were set into the ground to a depth of 12 inches thereby forming tanks which were 24 inches deep. A valve was provided for the inner ring so that the pools could be interconnected if desired. The water was obtained from the Poudre River for the Bellvue Laboratory rings and from the Fort Collins City water main for the Poudre Supply Plot. In either case the water was measured through calibrated domestic-type water meters. The water levels in the rings were controlled by float valves and variation in depths measured by hook gages mounted in each ring. Piezometers were installed at several locations around the rings as well as in the center rings in order to keep an accurate check on the ground water elevations.

Normally, twice daily readings were made of the seepage from the seepage rings. In addition, air temperatures were recorded as well as the water temperatures at both the water surface and the contact point with the soil. A standard Weather Bureau rain gage was used for measuring the precipitation. An evaporation pan was installed at the Poudre Supply Plot and these data were also used for the evaporation correction at the Bellvue Laboratory Plot.

Seepage Meters

Two types of seepage meters were used in the seepage studies. One

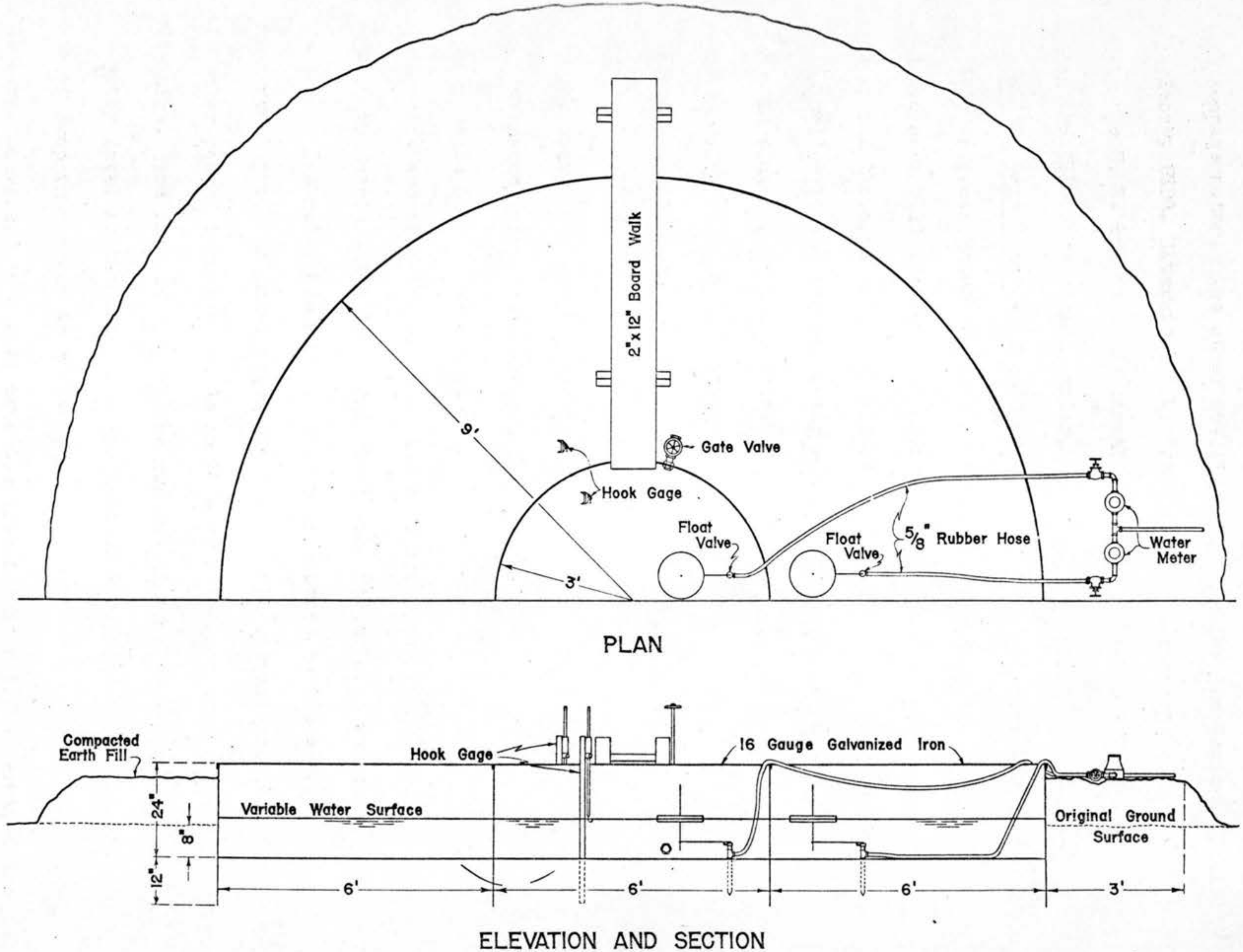


FIGURE 1.- SEEPAGE RINGS

type was developed by the Soil Conservation Service and is termed the SCS type seepage meter. The other was first designed by the Regional Salinity Laboratory, USDA, Riverside, California, and modifications were added after use by the U. S. Bureau of Reclamation. In this report this meter is called the USBR type seepage meter.

SCS Seepage Meter - The SCS seepage meter was described in detail in the 1950 Progress Report (8) and is shown in figures 2 and 3. The meter consists of a bell 12 inches in diameter and 6 inches deep with a sharpened edge around the open end to facilitate installation. The valve at the top of the bell was used for releasing entrapped air. A cup approximately 2 inches in diameter with a petcock attached near the base, was connected to the bell by means of a 1/2-inch rubber hose. The cup together with an attached hook gage was fastened to a stake which could be clamped to the outer ring wall. The hook gage was used to measure the drop in the cup when the valves were closed and the elevation of the water surface in the rings when the valves were opened.

To begin a test, water was first forced through the meter by closing the petcock and with the valve on the bell open, pouring water into the cup. This forced out the trapped air in the rubber hose and in the top of the bell. The hook gage and cup were then clamped to the outer ring wall and a reading of the water elevation taken. All valves were then closed and water poured into the cup to an inch or so higher than the outside water elevation. The rate of drop in the cup was timed with a stop watch until the water level in the cup was below that in the rings. The instantaneous rate of drop in the cup at the same time that the two water levels were the same, converted to a rate over the area of the bell, determined the seepage rate.

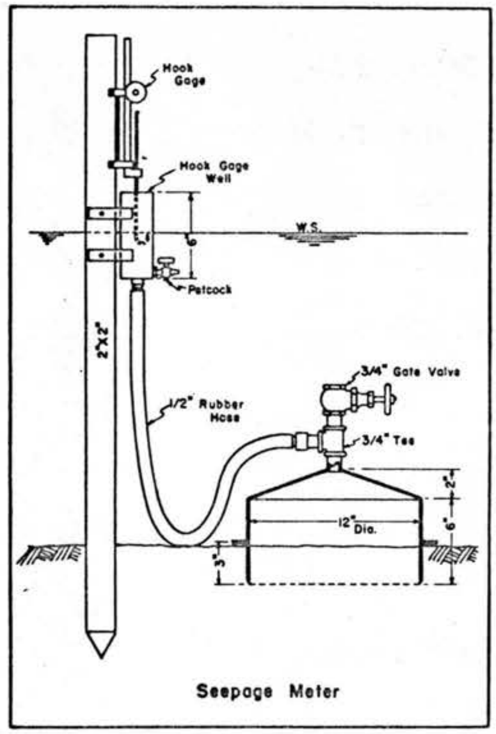


Figure 2.-- SCS seepage meter.

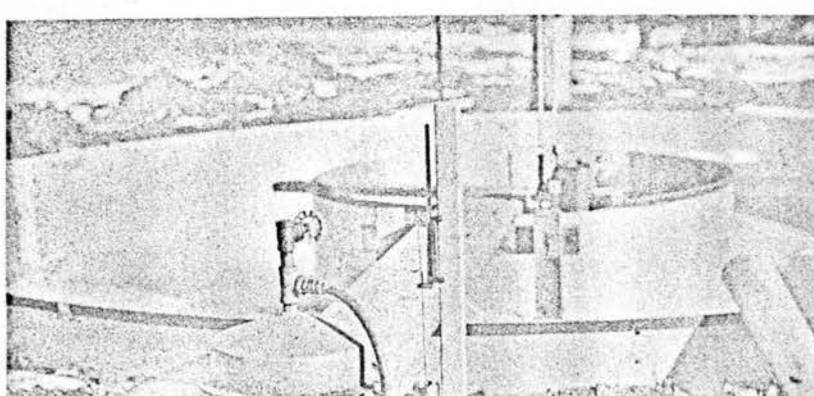


Figure 3.-- SCS seepage meter with metal bell.

Since it was believed that any jarring caused by hammering on the bell would materially affect the results of the tests, all installations were made either by standing on the bell or by jacking. In most cases, two men were able to force the meter down by gently rocking it with their feet.

In order to see if anything unusual occurred inside the meter after it was in place for a few days, a clear plastic meter was constructed, (figure 4.) This meter and attachments were practically the same as the one just described except that the bell was 10 inches in diameter. Another purpose of this meter was to let sunlight inside the bell so that it would not be dark as in the case of the meters made with sheet metal. It was thought that this absence of sunlight might be a reason for inconsistencies of the seepage meter readings.

USBR Seepage Meter - The USBR seepage meter is shown in figure 5. Briefly, this meter 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 with a flexible hose. The bell was installed in a manner similar to that used for the SCS meter. Care was taken to expell entrapped air by forcing water through the flexible tube with the valve on top of the bell open. The plastic bag was then filled with water, weighed, attached to the flexible hose and submerged in the surrounding water. In order to make a test, the valve at the top of the bell was closed and the clamp on the flexible hose opened. After a prescribed length of time the bag was removed and again weighed. This gave 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 Recla-

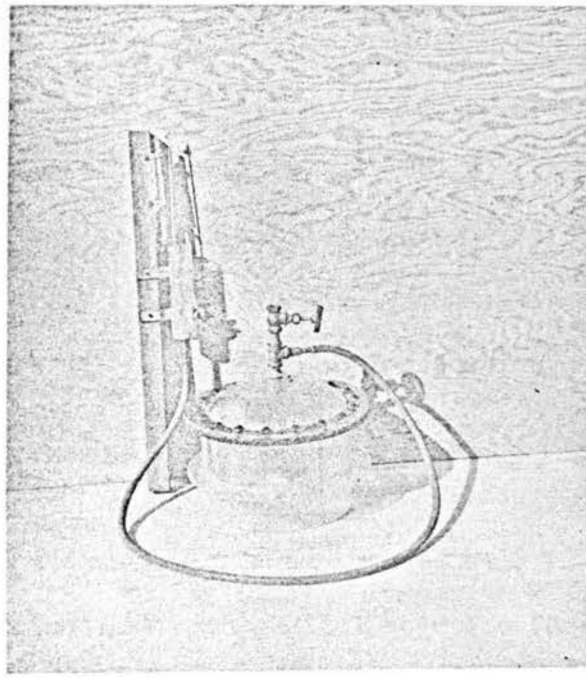


Figure 4.-- SCS seepage meter with plastic bell.

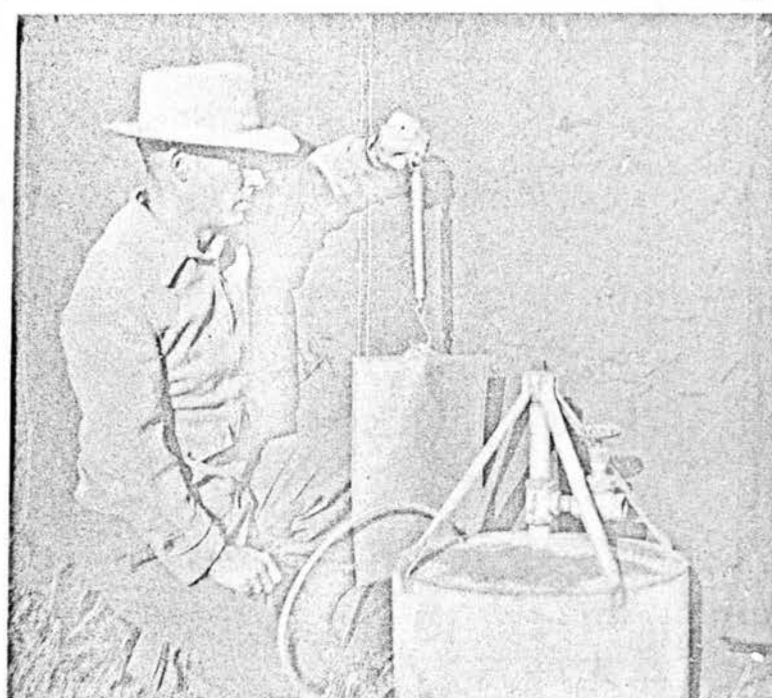


Figure 5.-- USBR seepage meter with plastic bag.

ration and is fully described in the Earth Manual (12). This permeameter consists of a calibrated supply tank equipped with an indicator glass and an outlet pipe equipped with the float mechanism (see figure 6). A hole 4 to 6 inches in diameter and varying in depth with the horizon to be tested was used. This hole was partly filled with highly permeable sand or gravel to reduce erosion and prevent caving and the top portion was equipped with a screen casing.

Essentially, the well permeameter tests consist of the measurement of a rate of water flowing outward and downward from an uncased well in which a constant head of water is maintained. A mathematical solution for determining the permeability coefficient K from the results has been developed by electrical analogy methods by the U. S. Bureau of Reclamation (12). For the case of the deep water table condition when the distance from the water surface in the hole to the water table is greater than three times the depth of water in the hole, the formula may be stated as:

$$K = 1,440 \left(\sinh^{-1}\left(\frac{h}{r}\right) - 1\right) \frac{Q}{2h^2} \qquad (1)$$

where h is the depth of water in the hole in feet, r is the radius of the hole in feet, Q is flow in cubic feet per minute required to maintain a constant water level and K is the permeability coefficient in feet per day.

Generally, the tests were continued for about ten days or two weeks until a fairly constant rate was being maintained. The Bureau Manual (12) specifies that the tests should be run only long enough to develop a saturated envelope in the soil. A minimum and maximum time limit on the duration of the test is presented. Readings were generally made at one-hour or two-hour intervals during the day. In addition to the tank reading, the temperature and depth of water in the hole were noted.

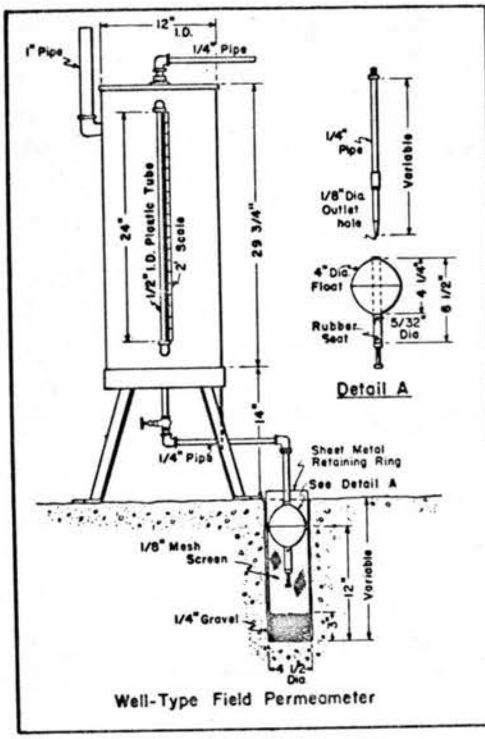


Figure 6.-- Well type permeameter.

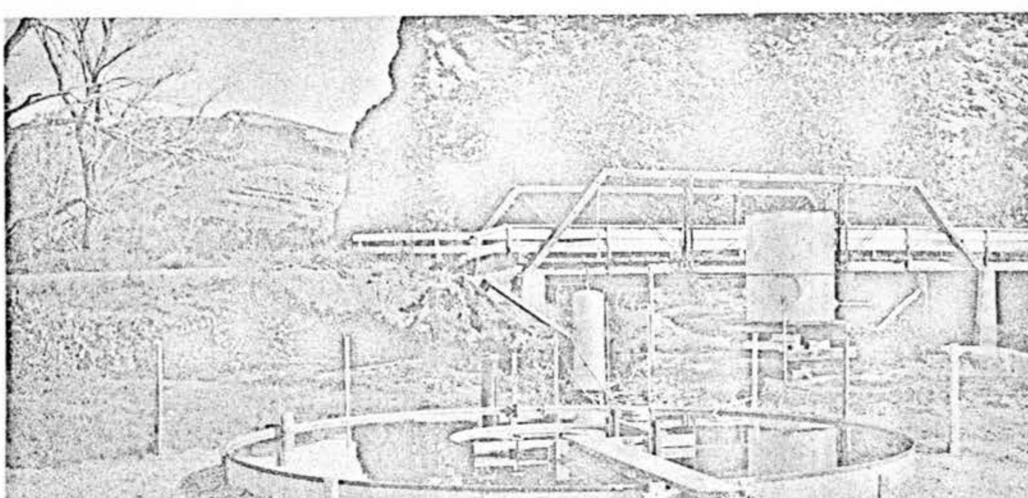


Figure 7.-- Seepage rings at Bellvue Plot with well type permeameter and settling tank in background.

PRESENTATION OF DATA

Bellvue Laboratory Seepage Tests

The seepage tests at the Bellvue Laboratory started in the summer of 1950 were continued in 1951. In addition to twice daily observations of the seepage from the seepage rings and the pertinent meteorological factors, weekly measurements of the ground water levels were made at the site. Tests were continued using the well-type permeameters in the vicinity of the rings and the seepage meters in the outer ring. In addition to the two types of SCS meters, the USBR seepage meter was also used for measuring the seepage from the rings.

Soil and Water Analysis - A report of the physical characteristics of the soil at the Bellvue plot is contained in the progress report submitted in 1951 (7). The mechanical analysis of the soil showed it to be a sandy loam. According to the Atterburg Classification Index the soil was classed as friable. A chemical analysis of the soil indicated it to be alkaline in reaction. The soluble salt content was very low and no gypsum was indicated. The analysis of the water used, which was taken directly from the Poudre River, is shown in table 1. This shows a low salt content and a water which is very nearly free of impurities.

Permeability tests of disturbed soil samples were made in the laboratory according to the procedure described in the 1950 progress report on soils (10) A plot of the results is given in the 1951 progress report (7). This shows a radical difference in the initial permeability of the samples. However, at the end of the 17-day period the rates were very nearly the same, approximately 4 feet per day for the 0 to 1-foot sample and 5 for the 1 to 2-foot sample.

Table I.-- 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
Cl - 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.

Seepage Rings - The site for the Bellvue Laboratory rings is on an island in the Poudre River. This site was selected because a highly permeable soil existed there and water was readily available. This island was built up by the river so that the soil profile consisted of large cobbles overlain with several feet of water deposited sand and silt. Because of the non-uniformity of the soil and the existence of lenses of coarse sand, the material inside the rings was excavated down to the cobbles, and then shoveled back into the rings so that it would be thoroughly mixed. This would tend to reduce the permeability of the soil from that of its natural state. The seepage rings are shown in figure 7.

Water was first turned into the rings for the 1951 season on June 4 after the water had been turned off since November 8, 1950. Twice-daily readings, were taken until November 1, when observations were again discontinued because of cold weather. Because of the relatively low seepage rate from the inner ring, water meters could not be used to measure the inflow and it was necessary to fill the ring at each reading and then allow the water to drop until the next reading to determine the seepage loss. However, water was allowed to flow into the outer ring continuously throughout the season with the inflow being measured with the water meter. 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.

A plot of the observed seepage rates as well as data on water depths, water temperature and barometric pressures is shown on figure 8. The seepage rates have been corrected for precipitation and evaporation. The outer ring started with an initial seepage rate of about 0.90 foot per day

Figure 8

Barometric Pressure
Water Temperature
Inches - Mercury
Degrees F
Seepage in Feet per Day
Feet
Leak Outer Ring Leak Stopped
Outer Ring Seepage
Inner Ring Seepage
Leak
Joints Repaired Bottom Raked
Hole Stilling Well Inner Ring Plugged
Continous Record
Rings Ran Over
Effect of Depth Test
Show
Well Probably Stopped Up
Water Depth
Legend
Drop Test
S. C. S. Seepage Meter
U. S. B. R. Seepage Meter
Plastic S. C. S. Seepage Meter
Bellvue Laboratory
Seepage Rings
1951
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
June
July
August
September
October

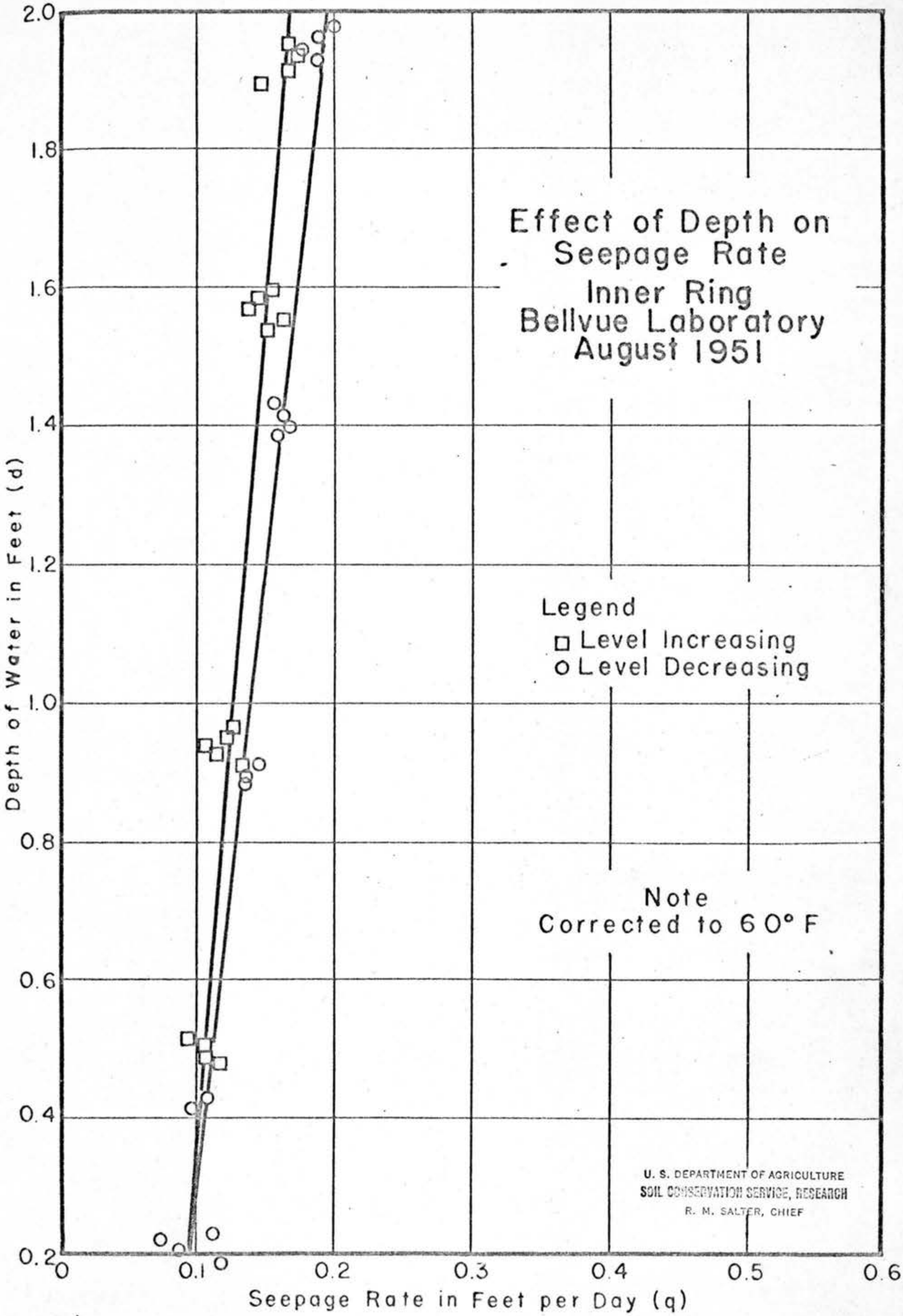
(cubic feet per square feet per day) and increased gradually for approximately three weeks until a rate of 1.30 feet per day was reached. A gradual decline in rate is then shown until the end of the test period when a rate of just over 0.20 foot per day was reached. A slight increase in seepage is noted about September 1 after a test in which the water level in the rings was allowed to drop almost to the bottom and then brought back to the maximum depth again. The increased head seemed to have the effect of temporarily increasing the rate above that caused by the additional depth of water.

The inner ring started the 1951 season at a rate of about 1.10 feet per day which was actually higher than the initial rate for the outer ring. However, the inner ring showed a gradual decrease throughout the entire period ending with a rate of about 0.15 foot per day. It is interesting to note that the initial rate from the outer ring is actually lower than the final rate for the previous season. The inner ring rate is higher but dropped to the same rate within two weeks and continued to drop until the end rate was approximately 1/4 that of the previous season.

On two occasions during the testing season the effect of depth of water in the seepage rings on the seepage rate was determined. For these tests, with the inflow shut off, the water was allowed to drop during the day noting the drop for hourly periods. At the end of the day the floats of the automatic controls were set down approximately 6 inches thereby lowering the water level 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.

Plots of these tests are shown on figures 9, 10, 11, and 12. For the inner ring the rates when successively dropped are very near those when

Figure 9


Effect of Depth on Seepage Rate
Inner Ring
Bellvue Laboratory
August 1951
Legend
□ Level Increasing
○ Level Decreasing
Note
Corrected to 60° F
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Depth of Water in Feet (d)
Seepage Rate in Feet per Day (q)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
0.1
0.2
0.3
0.4
0.5
0.6

Figure 10

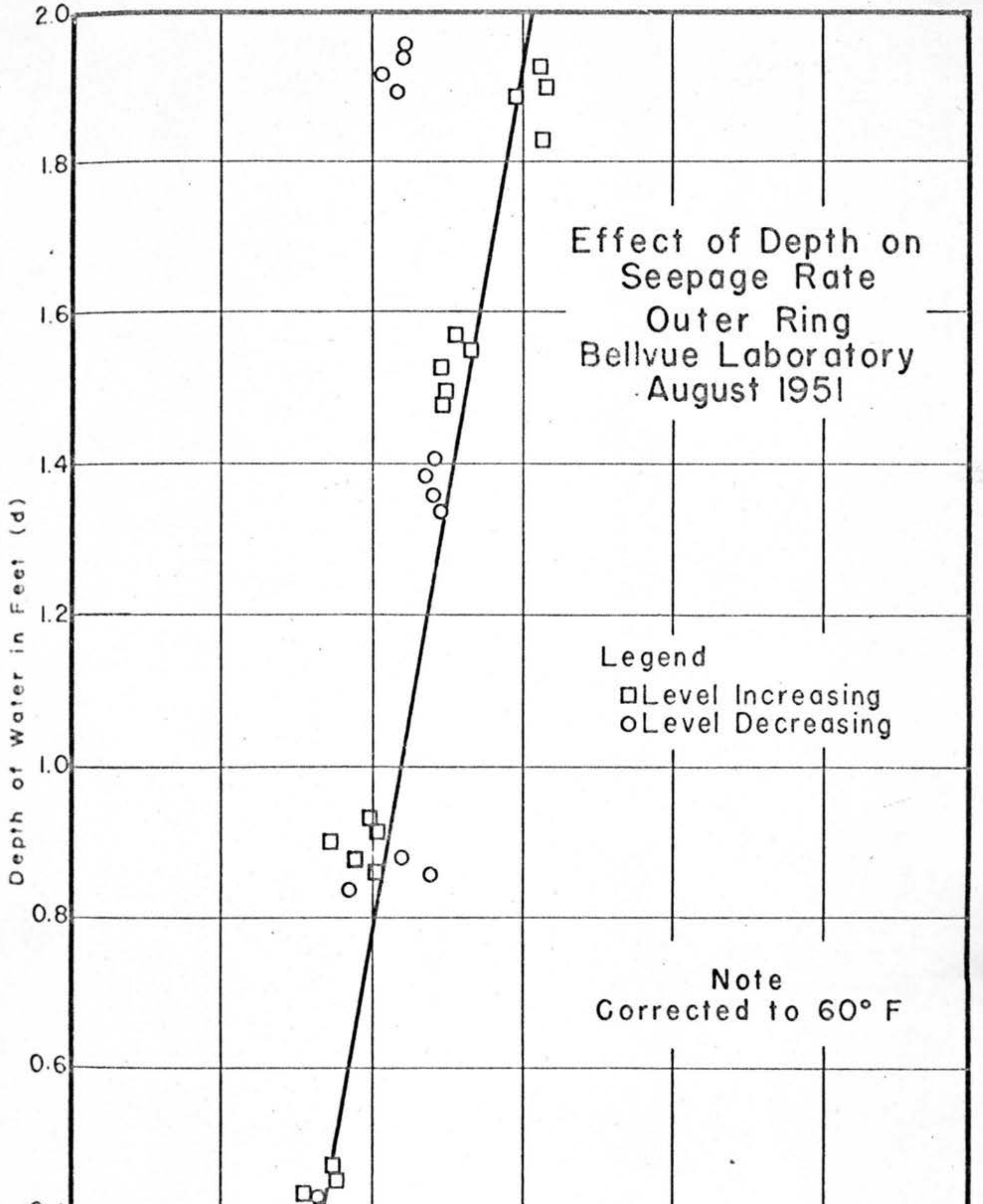
Effect of Depth on Seepage Rate
Outer Ring
Bellvue Laboratory
August 1951
Legend
Level Increasing
Level Decreasing
Note
Corrected to 60° F
Depth of Water in Feet (d)
Seepage Rate in Feet per Day (q)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
0.1
0.2
0.3
0.4
0.5
0.6
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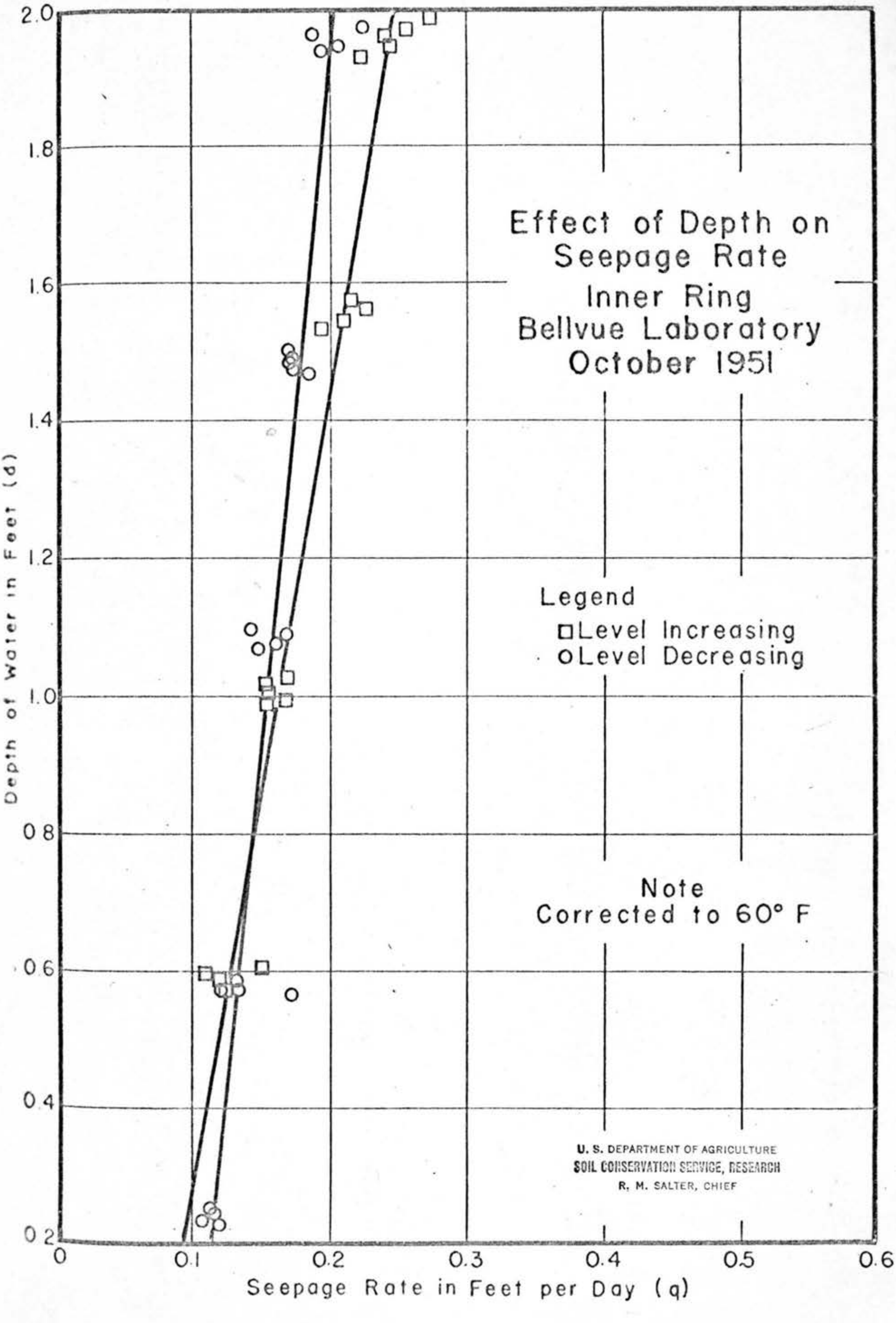
Figure 11



Effect of Depth on Seepage Rate
Inner Ring
Bellvue Laboratory
October 1951
Legend
□Level Increasing
○Level Decreasing
Note
Corrected to 60° F
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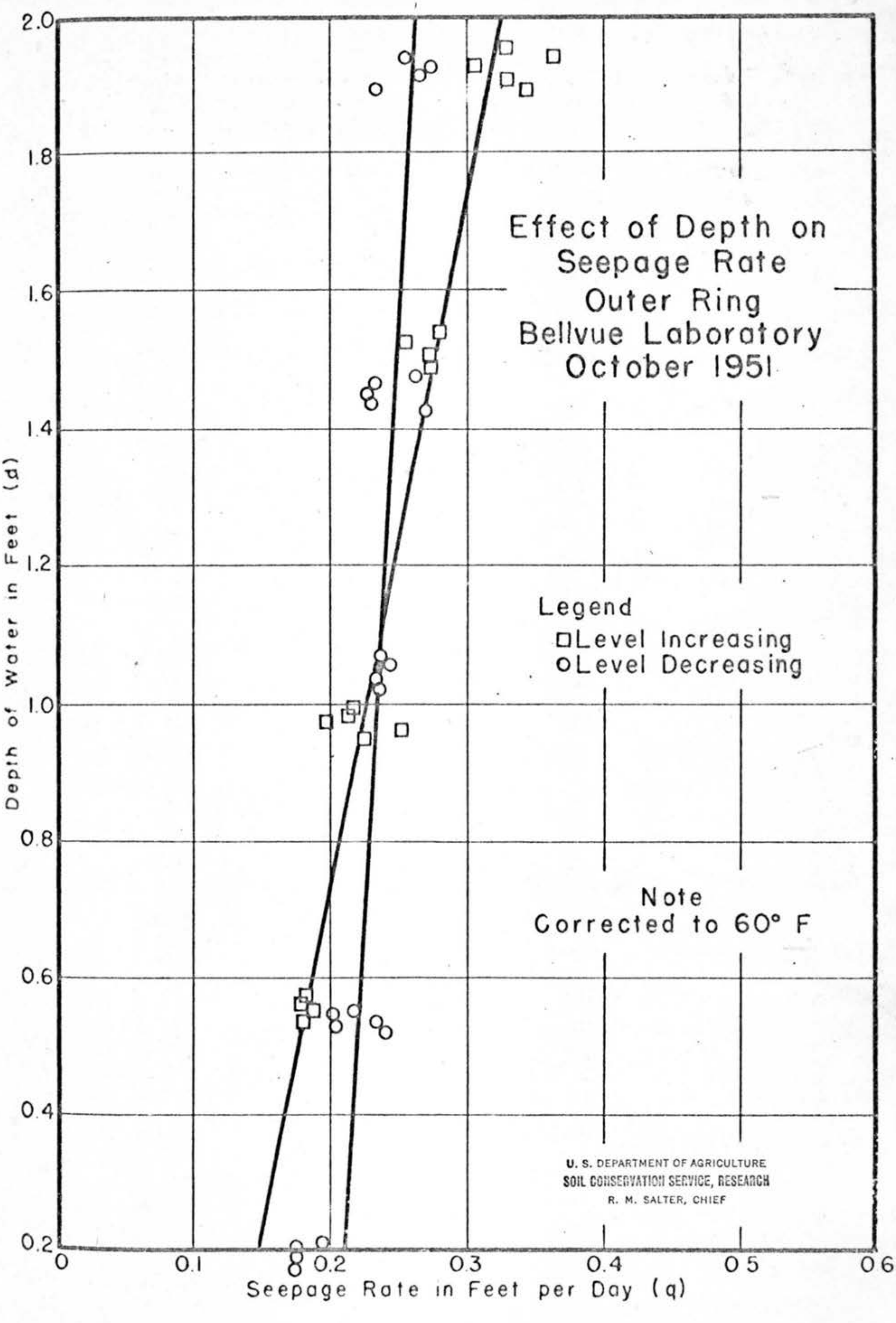
Depth of Water in Feet (d)
Seepage Rate in Feet per Day (q)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
0.1
0.2
0.3
0.4
0.5
0.6


Effect of Depth on
Seepage Rate
Outer Ring
Bellvue Laboratory
October 1951
Legend
□ Level Increasing
○ Level Decreasing
Note
Corrected to 60° F
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Depth of Water in Feet (d)
Seepage Rate in Feet per Day (q)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
0.1
0.2
0.3
0.4
0.5
0.6

successively raised for both the August and October tests. For the August determination the two rates were practically the same for the outer ring (see figure 10). However, there is a radical difference in the depth versus seepage rate for the October determination on the outer ring, figure 12.

A method of solving for the permeability K for the seepage rings was presented in the 1951 progress report. This method utilized the effect of depth plot for the inner ring. By projecting the lines representing the depth-seepage rate relationship until zero depth was reached, a value for the seepage rate was determined when the water level and the ground surface coincide. Using Darcy's equation:

$$q = K \frac{h}{l} \qquad (2)$$

where q is the rate of flow per unit area, K is the permeability, h is the hydraulic head and l is the length of the soil column. At zero depth of water above the ground surface, h and l are equal so that $\frac{h}{l}$ equals unity and q equals K at this point. This value of K is 0.085 foot per day for the August determination and approximately 0.100 for the October test for the inner ring.

In the 1950 progress report (7) another method of determining field permeabilities by the use of the seepage rings was presented. This method was developed by Mr. R. E. Glover of the U. S. Bureau of Reclamation (4). A cylinder which had been pressed into the soil for approximately half its length, is filled with water and the soil allowed to dampen to at least the bottom of the cylinder. The cylinder is then refilled with water and the time required for the water to drain away is noted. The formula developed by Glover is:

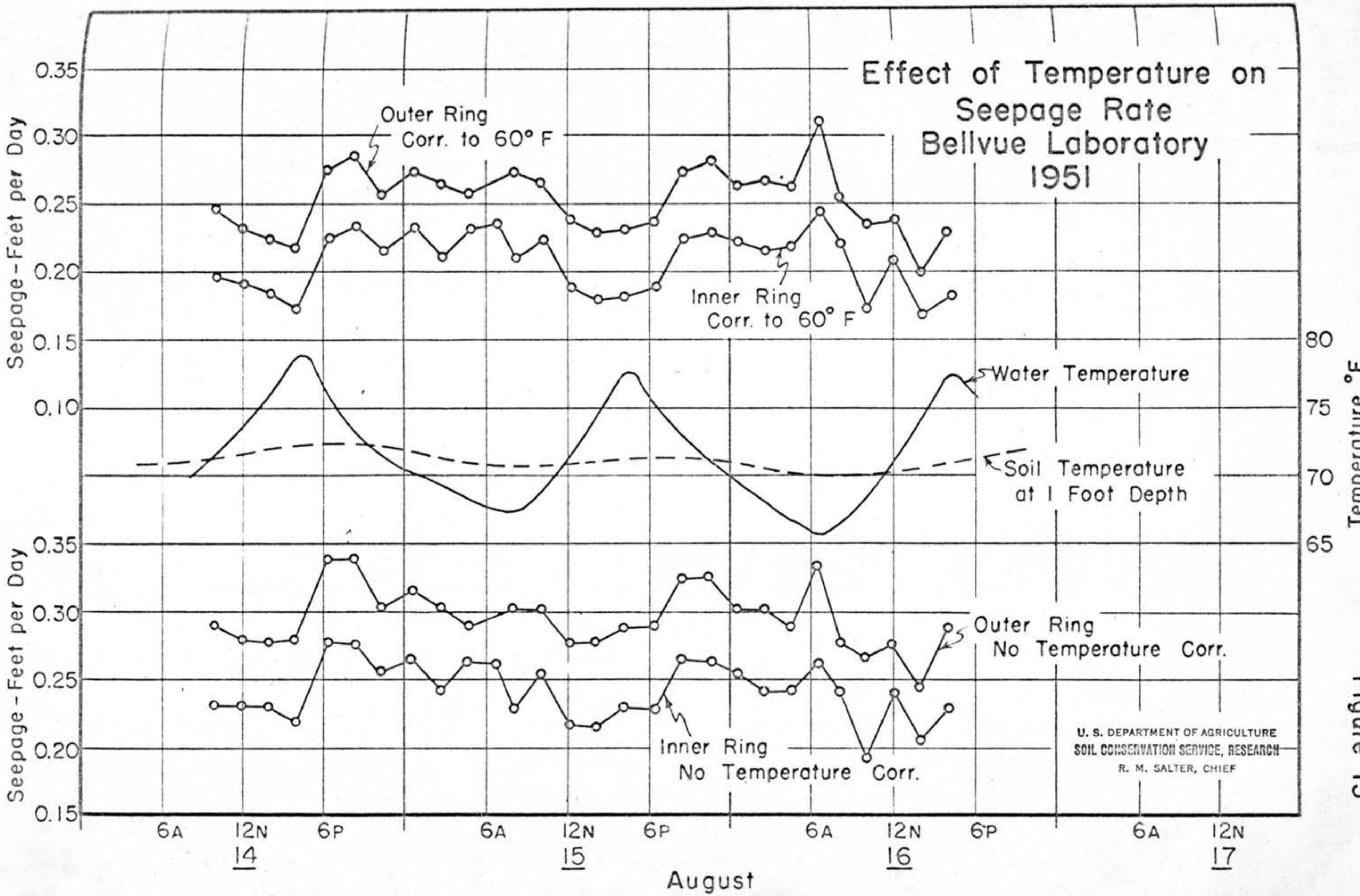
$$K = \frac{L}{T} \log_e \left(\frac{H+L+C}{L+C}\right) \qquad (3)$$

K is the permeability in feet per day, L is the equivalent length of cylinder through which percolation can be assumed to occur, T is the time for the water to be drained away after being filled to a depth H, and C is the capillary tension. For the Bellvue seepage rings the depth H was approximately 2 feet and the equivalent length L was the embedded length (1 foot) plus 0.285 times the diameter. The soil was assumed to be saturated because water had been in the rings for two months, so that C was zero. The following tabulation shows the permeability as determined by this method as well as that obtained by the "Effect of Depth" tests.

Date 1951	Seepage Ring	Permeability K Glover Ft/day	Permeability K Effect of Depth Ft/day
Aug.	Inner	0.100	0.085
Oct.	Inner	0.119	0.090
Aug.	Outer	0.190	0.135
Oct.	Outer	0.198	0.170

These tests give a fairly close correlation in the determination of the permeability by the two methods.

After the rings had been operating for approximately 2-1/2 months it became apparent that although the seepage rate, as shown by the twice daily observations was fairly constant, there seemed to be a variation in rate from hour to hour as shown by the drop tests. To check this variation the rate of drop was measured for two hour periods continuously for over two days. Figure 13 is a plot of the results. Shown are the inner and outer ring rates corrected only for evaporation and those corrected for both evaporation and temperature. This plot shows variations which could not



Effect of Temperature on
Seepage Rate
Bellvue Laboratory
1951
Outer Ring
Corr. to 60° F
Inner Ring
Corr. to 60° F
Water Temperature
Soil Temperature
at 1 Foot Depth
Outer Ring
No Temperature Corr.
Inner Ring
No Temperature Corr.
Seepage-Feet per Day
Seepage - Feet per Day
Temperature °F
0.35
0.30
0.25
0.20
0.15
0.10
80
75
70
65
6A
12N
6P
14
15
16
17
August
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Figure 13

be attributed to errors in observation since the rings were independently operated and there are variations which are common to both rings. The lowest seepage rates are essentially opposite the highest water temperatures with the higher rates approximately four hours later.

Figure 13 also shows plotted to the same scale as the water temperature, the soil temperature at one foot depth which was determined at another location where only natural vegetative cover existed. The soil temperature at one foot depth under the seepage rings probably differed from this temperature because of the insulation of the two-foot depth of water. However, this is presented as a possible reason for the 50 percent variation in seepage rates over a period of a few hours. The increasing temperature of the water as it percolates through the soil causes deposition of air in the form of bubbles which clog the openings. Conversely, for a decreasing temperature of the water air would be held in solution in the water and the air in the soil would be dissolved thereby increasing the permeability in the soil.

In order to determine the effect of the seepage from the seepage rings on the ground water elevations, piezometers were installed around the rings and in a line leading toward the Poudre River. Weekly measurements were made of the water levels in the piezometers and the elevation of the water in the river. Figure 14 shows the results. The fluctuations in the ground water elevations seem to be due only to the fluctuation of stage of the Poudre River nearby. This is true of the piezometers in the inner ring as well as those outside the seepage rings.

Seepage Meter Tests - During the 1951 season ninety-five determinations of the seepage rate at the Bellvue rings were made with seepage meters.

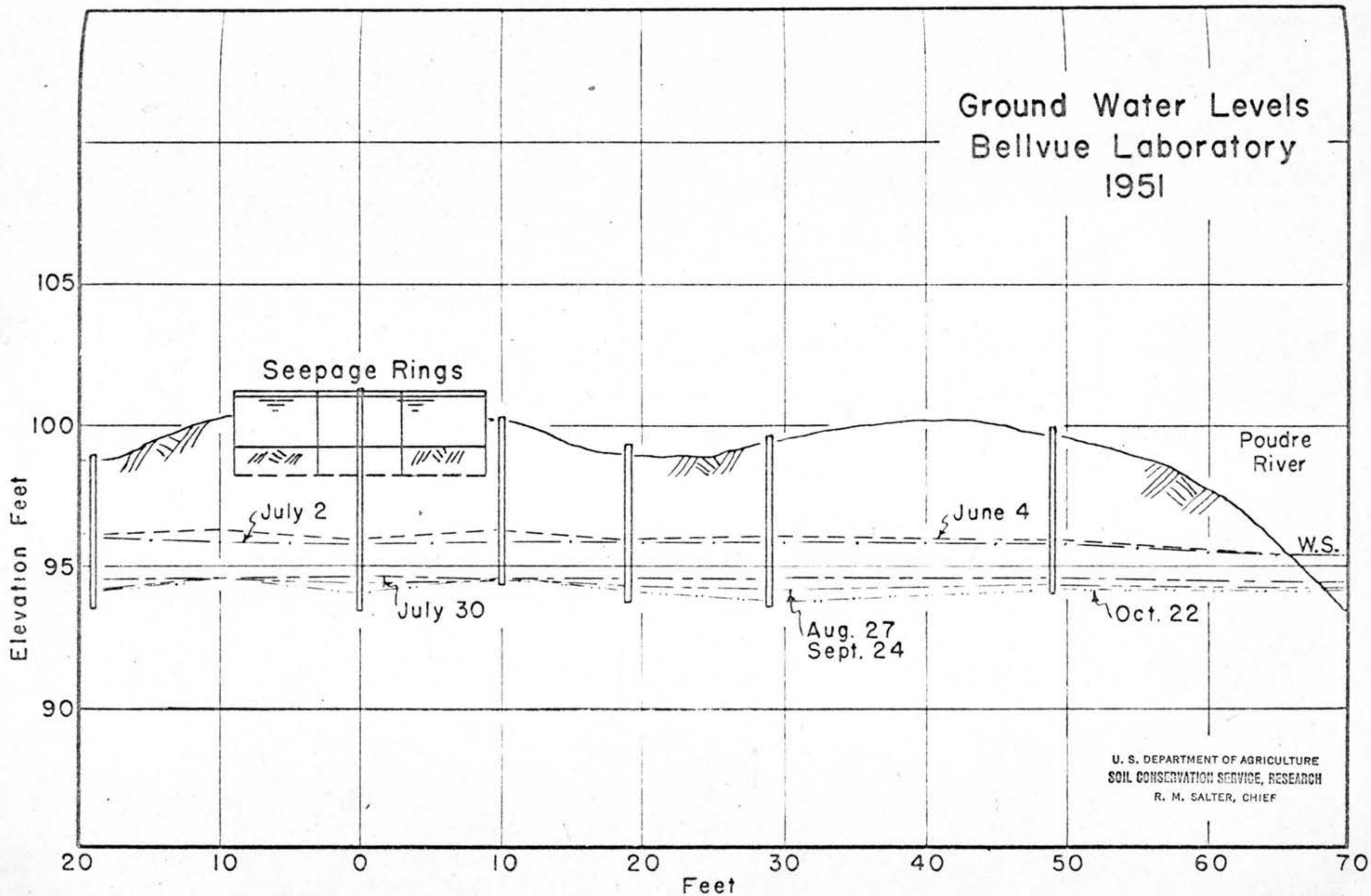

Ground Water Levels
Bellvue Laboratory
1951
Seepage Rings
Poudre
River
July 2
June 4
W.S.
July 30
Aug. 27
Sept. 24
Oct. 22
105
100
95
90
Elevation Feet
20
10
0
10
20
30
40
50
60
70
Feet
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, RESEARCH
R. M. SALTER, CHIEF

Figure 14

Over sixty of these tests were made with the SCS seepage meter with each test immediately repeated as a check. The SCS meter and the Bureau meters were generally installed side by side in the outer ring and left in place for periods ranging from a week to two weeks. The first seepage determination was usually made within a day after installation with further tests continuing at two-day intervals.

The results of the tests are shown plotted on figure 8 and are tabulated in table 2. Comparisons of these results show that relatively, the rates found by the two methods are of the same order. However, quantitatively there are some fairly large variations. Generally, the seepage meter rates are greater than the inner ring rates and less than the outer ring rates.

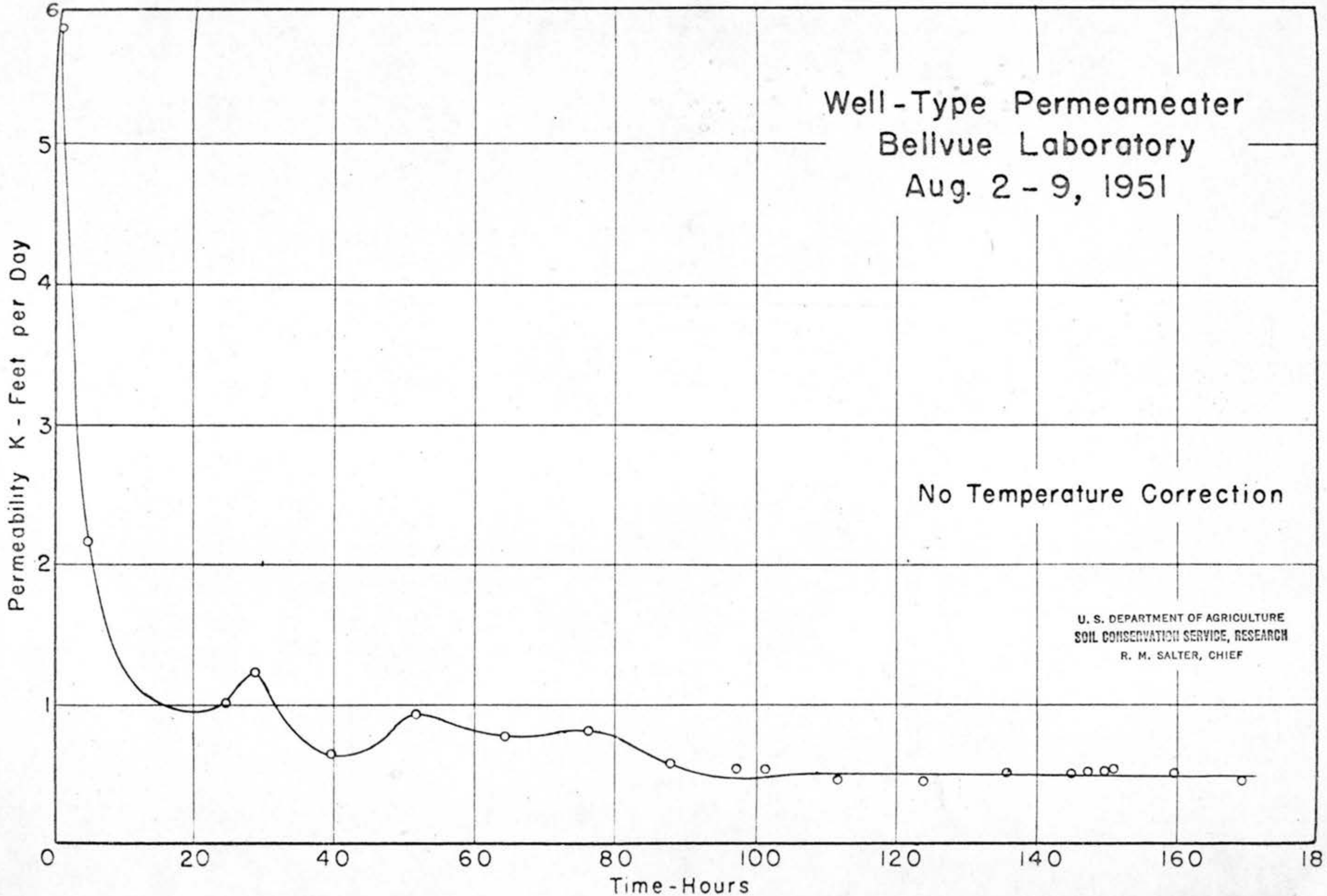
Well-type Permeameter Tests - For the purpose of comparing the permeabilities as shown by the well-type permeameters and those determined by the seepage meters and rings, tests were made at a number of locations around the outside of the rings. In addition, one test was made inside the outer ring after the water had been shut off and the ground surface dried up. Figures 15, 16 and 17 are representative tests out of 10 individual tests made during the season around the outside of the rings. Values of K, after constant rates were attained, range from 0.25 to 0.50 feet per day. High initial rates of from 5 to 6 feet per day are shown. However, for the test made within the outer ring, a constant rate of near 1.80 feet per day is shown. (See figure 18).

Poudre Supply Plot Seepage Tests

The seepage tests at the Poudre Supply plot were started in 1951. This site was selected because of the existence of a fairly heavy clay soil and the availability of water from the Ft. Collins City water line.

Table 2.-- Comparison of Seepage Ring and Seepage Meter Measurements of Seepage, Bellvue Laboratory Plot.

Time	Water Depth	Seepage Rings Inner Rate	Seepage Rings Outer Rate	Seepage Meters SCS Loc.	SCS Rate	Plastic SCS Loc.	Plastic SCS Rate	USBR Loc.	USBR Rate
1951	Ft.	Ft/day	Ft/day		Ft/day		Ft/day		Ft/day
6-19	1.92	0.72	1.11	A	1.34				
6-21	1.92	0.51	0.99	A	1.08				
6-23	1.93	0.48	1.03	A	0.92				
6-25	1.91	0.57	1.20	A	0.93				
6-27	1.92	0.52	1.27	A	0.80				
6-29	1.92	0.47	1.26	A	0.84				
7-2	1.88	0.54	1.18	A	1.06			1	1.59
7-4	1.91	0.45	1.00	A	0.84			1	1.25
7-6	1.91	0.42	0.82	A	1.07			1	1.09
7-11	1.94	0.36	0.72	B	0.66			2	2.23
7-13	1.90	0.37	0.68	B	0.42			2	1.18
7-16	1.93	0.33	0.56	B	0.35			2	1.16
7-18	1.91	0.32	0.55	B	0.30			2	0.95
7-20	1.92	0.32	0.55	B	0.30			2	0.92
7-24	1.91	0.31	0.57			C	1.43		
7-26	1.98	0.30	0.52			C	1.05		
7-27	1.97	0.27	0.46			C	0.79		
7-29	1.94	0.29	0.43			C	0.58		
8-8	1.95	0.23	0.32	D	0.24			3	0.31
8-10	1.93	0.25	0.29	D	0.24			3	0.30
8-13	1.93	0.24	0.33	D	0.25			3	0.29
8-17	1.90	0.22	0.23	D	0.23			3	0.24
8-22	1.95	0.21	0.24	D	0.19	EE	1.09	3	0.22
8-23	1.95	0.21	0.24			EE	0.84		
8-24	1.37	0.18	0.24			EE	0.85		
9-5	1.95	0.19	0.40	E	0.25			4	0.40
9-7	1.95	0.19	0.42	E	0.21	F	0.82	4	0.33
9-10	1.95	0.19	0.39	E	0.18	F	0.46	4	0.28
9-12	1.95	0.17	0.33	E	0.15	F	0.35	4	0.36
9-14	1.95	0.17	0.33	E	0.16	F	0.34	4	0.25
9-17	1.95	0.17	0.33	E	0.15	F	0.34	4	0.24
9-19	1.95	0.17	0.37	G	0.96	H	0.68	5	0.95
9-21	1.95	0.18	0.41	G	0.88	H	0.56	5	0.72
9-24	1.95	0.17	0.38	G	0.99	H	0.71	5	0.62
9-26	1.95	0.16	0.36	G	0.89	H	0.68	5	0.57
9-28	1.95	0.18	0.40	G	0.83	H	0.44	5	0.55
10-2	1.95	0.14	0.37	I	0.27	J	0.29	6	0.44
10-3	1.95	0.17	0.41	I	0.25	J	0.26	6	0.39
10-6	1.95	0.17	0.36	I	0.21	J	0.21	6	0.33
10-9	1.95	0.17	0.39	I	0.20	J	0.21	6	0.32
10-12	1.95	0.20	0.37	I	0.20	J	0.22	6	0.31
10-16	1.95	0.19	0.33	K	0.31	L	0.41	7	0.28
10-19	1.95	0.15	0.24	K	0.25	L	0.31	7	0.23
10-24	1.45	0.14	0.22	K	0.24	L	0.23	7	0.18



Well-Type Permeameater
Bellvue Laboratory
Aug. 2 - 9, 1951
No Temperature Correction
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, RESEARCH
R. M. SALTER, CHIEF
Permeability K - Feet per Day
Time - Hours
0
20
40
60
80
100
120
140
160
180
1
2
3
4
5
6

Figure 15

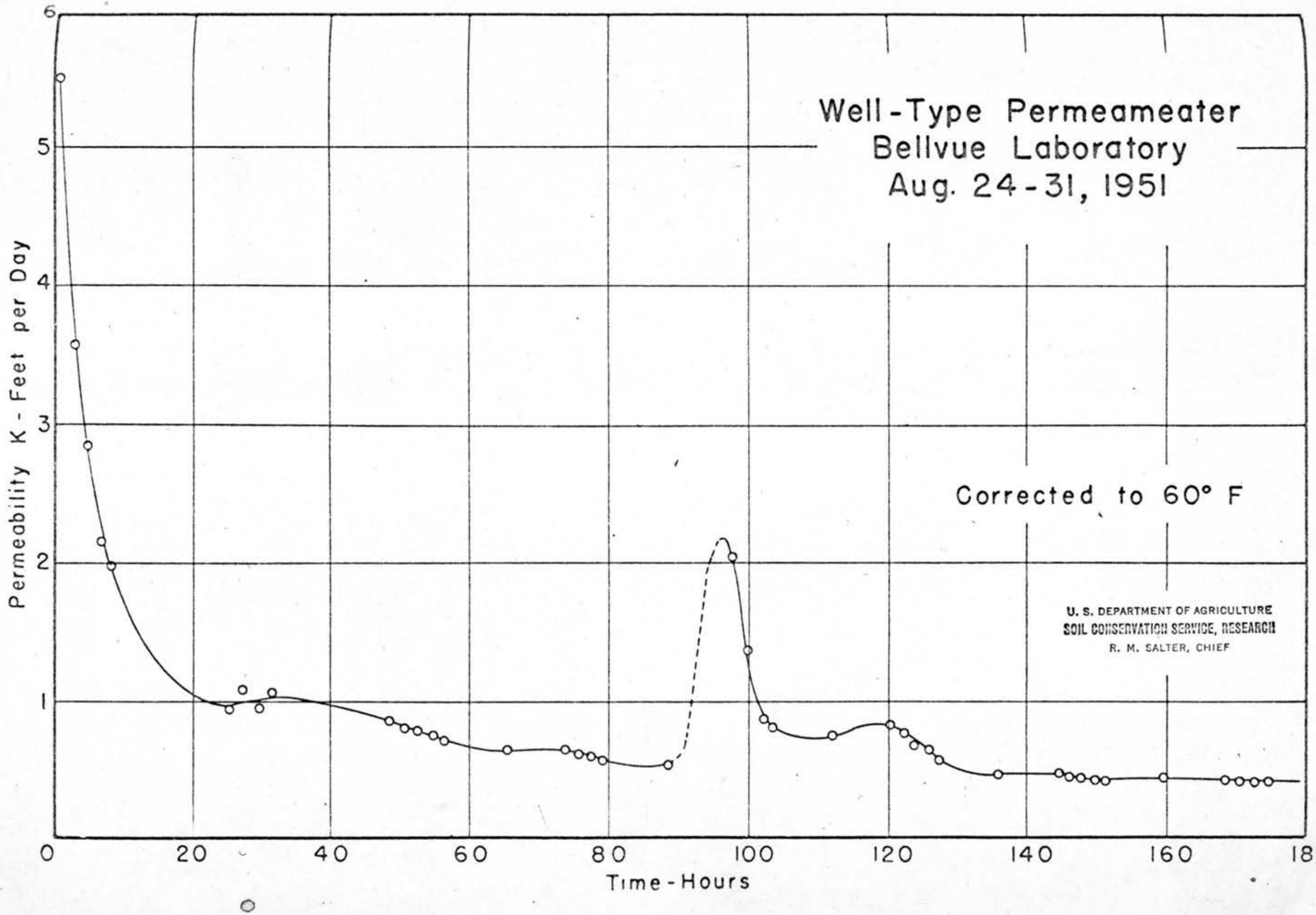

Well-Type Permeameater
Bellvue Laboratory
Aug. 24-31, 1951
Corrected to 60° F
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, RESEARCH
R. M. SALTER, CHIEF
Permeability K - Feet per Day
Time - Hours
0
20
40
60
80
100
120
140
160
180
1
2
3
4
5
6

Figure 16

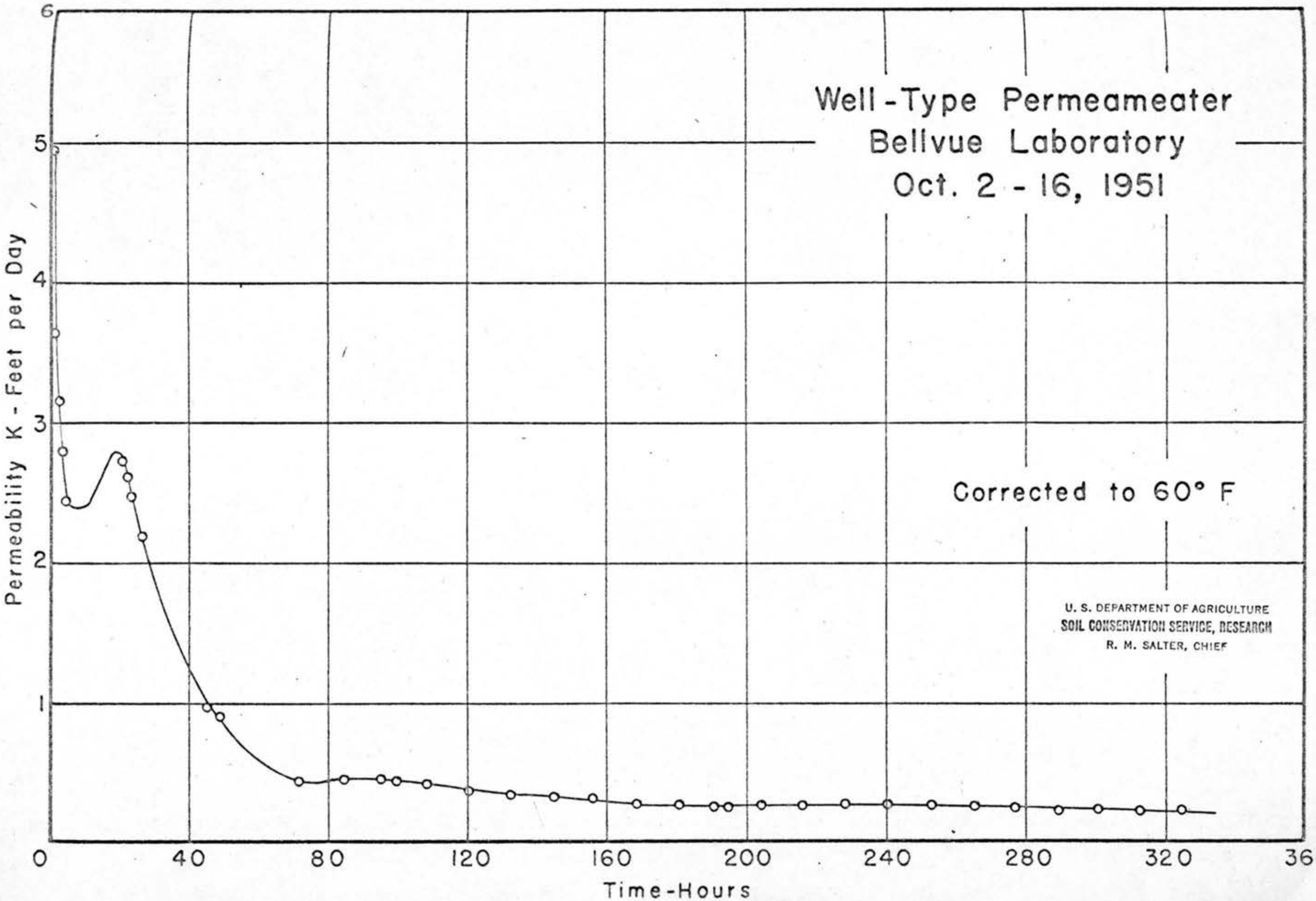

Well-Type Permeameater
Bellvue Laboratory
Oct. 2 - 16, 1951
Corrected to 60° F
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, RESEARCH
R. M. SALTER, CHIEF
Permeability K - Feet per Day
Time-Hours
0
1
2
3
4
5
6
40
80
120
160
200
240
280
320
360

Figure 17

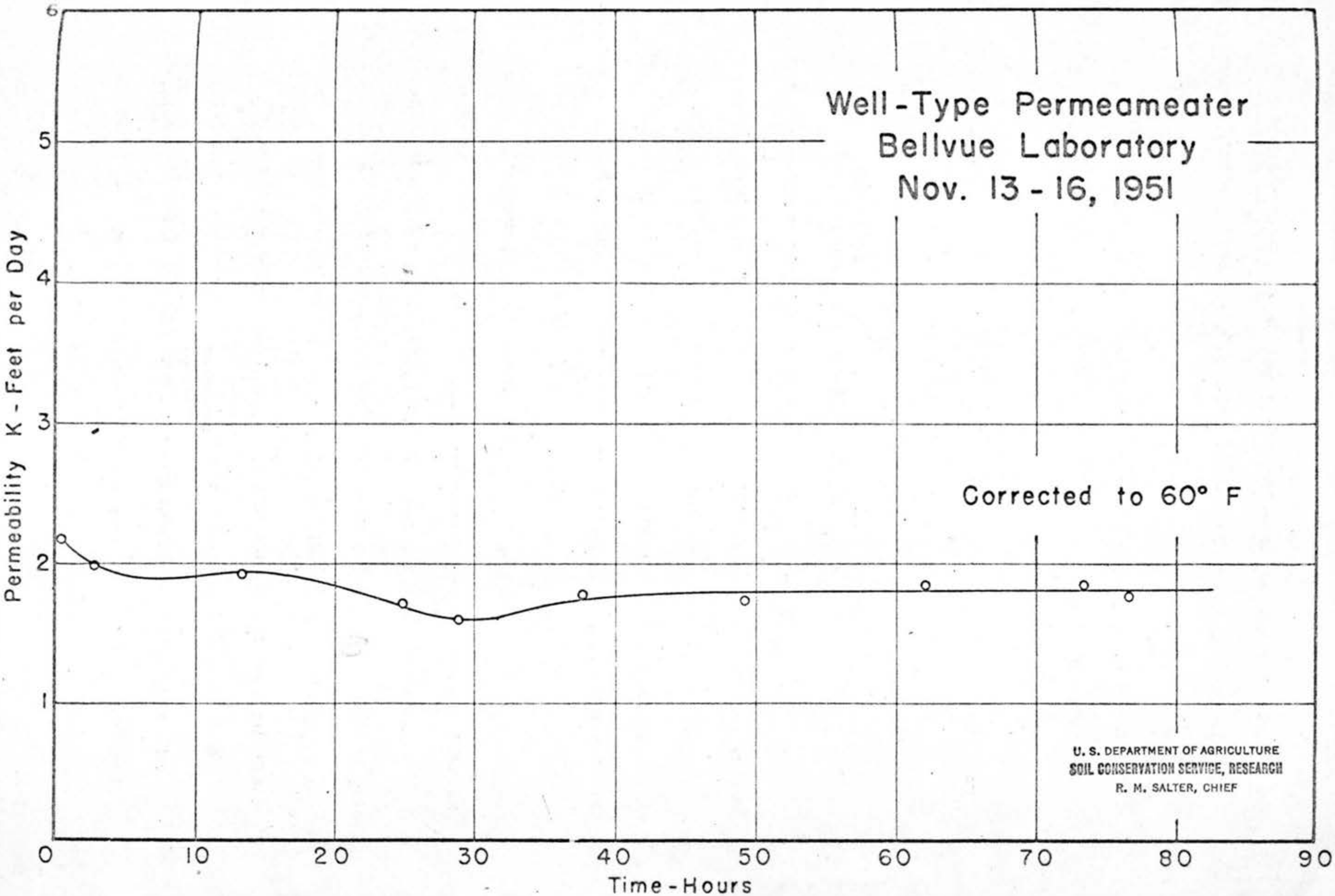

Well-Type Permeameater
Bellvue Laboratory
Nov. 13 - 16, 1951
Corrected to 60° F
Permeability K - Feet per Day
Time - Hours
0
1
2
3
4
5
6
10
20
30
40
50
60
70
80
90
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, RESEARCH
R. M. SALTER, CHIEF

Figure 18

Soil and Water Analysis - For the purpose of making a study of the soil characteristics, soil samples were taken with a soil auger at two locations on opposite sides of the seepage rings. Samples were taken each foot down to 7 feet at one location and to a depth of 8 feet at the other location. Tests and measures taken to indicate the detailed nature of the soil in this area include:

a. Atterburg limits

b. Mechanical analyses

c. Salinity tests

d. Disturbed permeability tests

A summary of these tests is given in tables 3, 4, and 5.

The liquid limit, plastic limit and plasticity index were determined in accordance with methods set forth by the American Society of Testing Materials. The plasticity index which is a measure of the moisture content over which a soil is plastic has a large value for the 0-1 foot sample on the east side and for the 0-1 and 1-2 foot samples on the west side of the seepage rings. This would indicate that the soil was highly impermeable for those depths. For greater depths, a classification of feebly plastic to friable was determined using the Atterburg Classification Index.

The mechanical analysis of the soil was made using the procedure presented by the American Society of Testing Materials. Sodium silicate was used as the dispersion agent. Size distribution curves for each of the sampling locations are shown in figures 19 and 20 and a summary of the results is given in table 5. The soil was classified according to the U. S. Bureau of Soils specifications. For the location on the east side of the rings a loam soil existed for the first one foot depth. From one

Table 3.-- Soil Analysis - Poudre Supply Plot

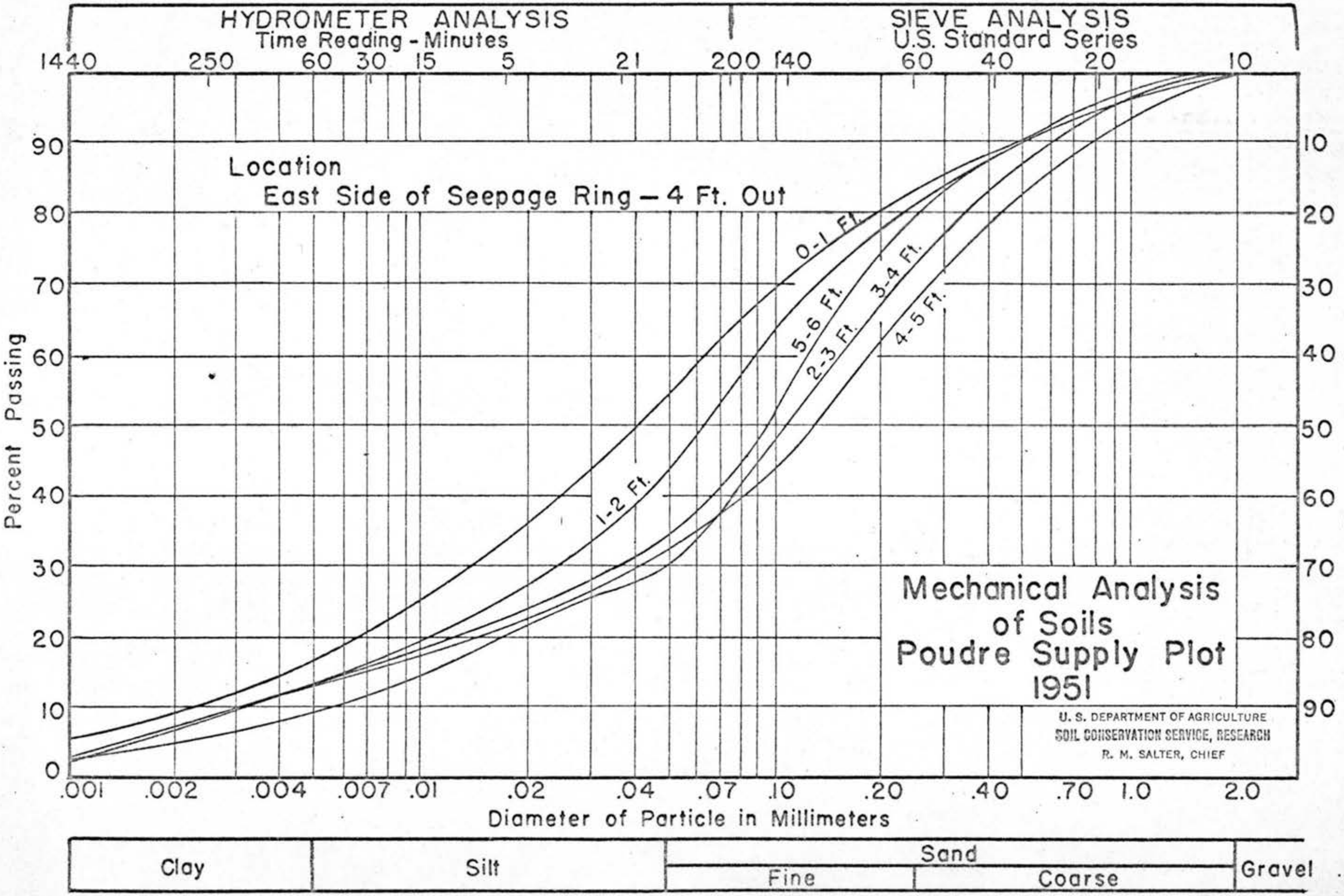
Sample Depth Feet	Liquid Limit	Plastic Limit	Plasticity Index	Atterburg Classification Index	Bureau of Soils Classification	K Disturbed Sample Ft/day
East Side of Seepage Rings - 4 feet out.						
0-1	38.9	19.9	19.0	Highly Plastic	Loam	0.20
1-2	30.7	20.1	10.6	Medium Plastic	Sandy Loam	0.90
2-3	25.0	19.1	5.9	Feebly Plastic	Sandy Loam	0.70
3-4	23.8	21.8	2.0	Feebly Plastic	Sandy Loam	1.20
4-5	23.9	19.9	4.0	Feebly Plastic	Sandy Loam	0.80
5-6.8	18.5	18.2	0.3	Friable	Sandy Loam	--
West Side of Seepage Rings - 4 feet out.						
0-1	52.8	27.0	25.8	Highly Plastic	Silty Clay	0.05
1-2	48.8	22.6	26.2	Highly Plastic	Silty Clay	0.03
2-3	29.2	19.2	10.0	Medium Plastic	Sandy Loam	0.35
3-4	24.5	16.3	8.2	Medium Plastic	Sandy Loam	0.18
4-5	23.7	16.7	7.0	Feebly Plastic	Sandy Loam	0.22
5-7.9	19.2	16.1	3.1	Feebly Plastic	Sandy Loam	0.45

Table 4.-- Chemical Analysis of Soils
Poudre Supply Plot

Depth Sample	pH Paste	pH 1:5	Total Soluble Salts	Total Grav. Salts	Organic Material	$CaCO_3$ (Lime)
Feet			Percent	Percent	Percent	Percent
East Side of Seepage Rings - 4 feet out.						
0-1	7.1	7.4	0.11	<0.5	1.2	0.4
1-2	7.1	7.3	0.08	<0.5	0.9	0.5
2-3	7.2	7.3	0.05	<0.5	0.7	0.4
3-4	7.6	7.8	< 0.02	<0.5	0.6	13.4
4-5	7.6	7.9	< 0.02	<0.5	0.3	18.8
5-6.8	7.7	8.0	< 0.02	<0.5	0.2	26.6
West Side of Seepage Rings - 4 feet out.						
0-1	6.2	6.9	0.13	<0.5	1.5	0
1-2	6.6	7.0	0.11	<0.5	1.2	0
2-3	7.4	7.6	0.08	<0.5	0.7	1.6
3-4	7.4	7.6	0.05	<0.5	0.5	1.6
4-5	7.4	7.6	0.05	<0.5	0.6	0.7
5-7.9	7.7	7.9	< 0.02	<0.5	0.2	9.5

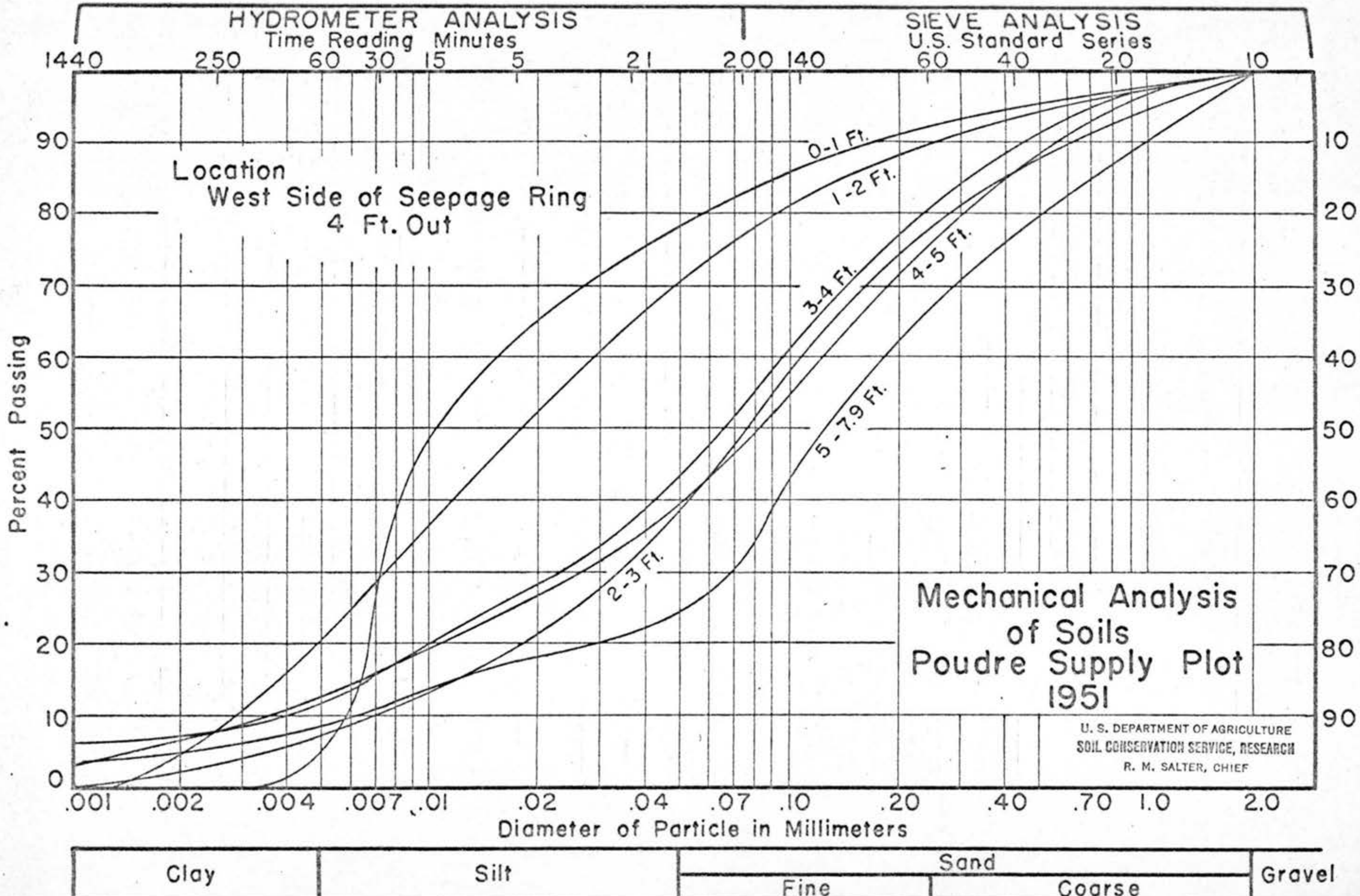
Table 5.-- Combined Mechanical Analysis of Soils
Poudre Supply Plot

Sample Depth	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
Feet	Percent	Percent	Percent	Percent	Percent	Percent	
			East Side of Seepage Rings - 4 feet out.				
0-1	5.5	11.0	38.5	28.0	17.0	0	Loam
1-2	3.0	11.0	29.0	38.5	18.5	0	Sandy Loam
2-3	3.0	6.5	20.5	43.0	27.0	0	Sandy Loam
3-4	2.0	8.0	22.0	41.0	27.0	0	Sandy Loam
4-5	4.0	10.0	19.0	36.0	31.0	0	Sandy Loam
5-6.8	2.0	11.0	21.0	46.0	20.0	0	Sandy Loam
			West Side of Seepage Rings - 4 feet out.				
0-1	0.0	5.0	73.0	15.0	7.0	0	Silty Clay
1-2	0.0	20.0	51.0	19.0	10.0	0	Silty Clay
2-3	0.0	7.0	31.0	40.0	22.0	0	Sandy Loam
3-4	6.5	5.5	31.0	38.0	19.0	0	Sandy Loam
4-5	4.0	9.0	26.0	37.0	24.0	0	Sandy Loam
5-7.9	4.0	5.0	15.0	43.0	33.0	0	Sandy Loam



HYDROMETER ANALYSIS
Time Reading - Minutes
1440 250 60 30 15 5 21
SIEVE ANALYSIS
U.S. Standard Series
200 140 60 40 20 10
Location
East Side of Seepage Ring — 4 Ft. Out
0-1 Ft.
1-2 Ft.
2-3 Ft.
3-4 Ft.
4-5 Ft.
5-6 Ft.
Mechanical Analysis
of Soils
Poudre Supply Plot
1951
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, RESEARCH
R. M. SALTER, CHIEF
Percent Passing
0 10 20 30 40 50 60 70 80 90
Percent Retained
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
Diameter of Particle in Millimeters
Clay
Silt
Sand
Fine
Coarse
Gravel

Figure 19



HYDROMETER ANALYSIS
Time Reading Minutes
1440 250 60 30 15 5 2 1
SIEVE ANALYSIS
U.S. Standard Series
200 140 60 40 20 10
Location
West Side of Seepage Ring
4 Ft. Out
0-1 Ft.
1-2 Ft.
2-3 Ft.
3-4 Ft.
4-5 Ft.
5-7.9 Ft.
Percent Passing
Percent Retained
Mechanical Analysis
of Soils
Poudre Supply Plot
1951
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, RESEARCH
R. M. SALTER, CHIEF
.001 .002 .004 .007 .01 .02 .04 .07 .10 .20 .40 .70 1.0 2.0
Diameter of Particle in Millimeters
Clay
Silt
Sand
Fine
Coarse
Gravel

Figure 20

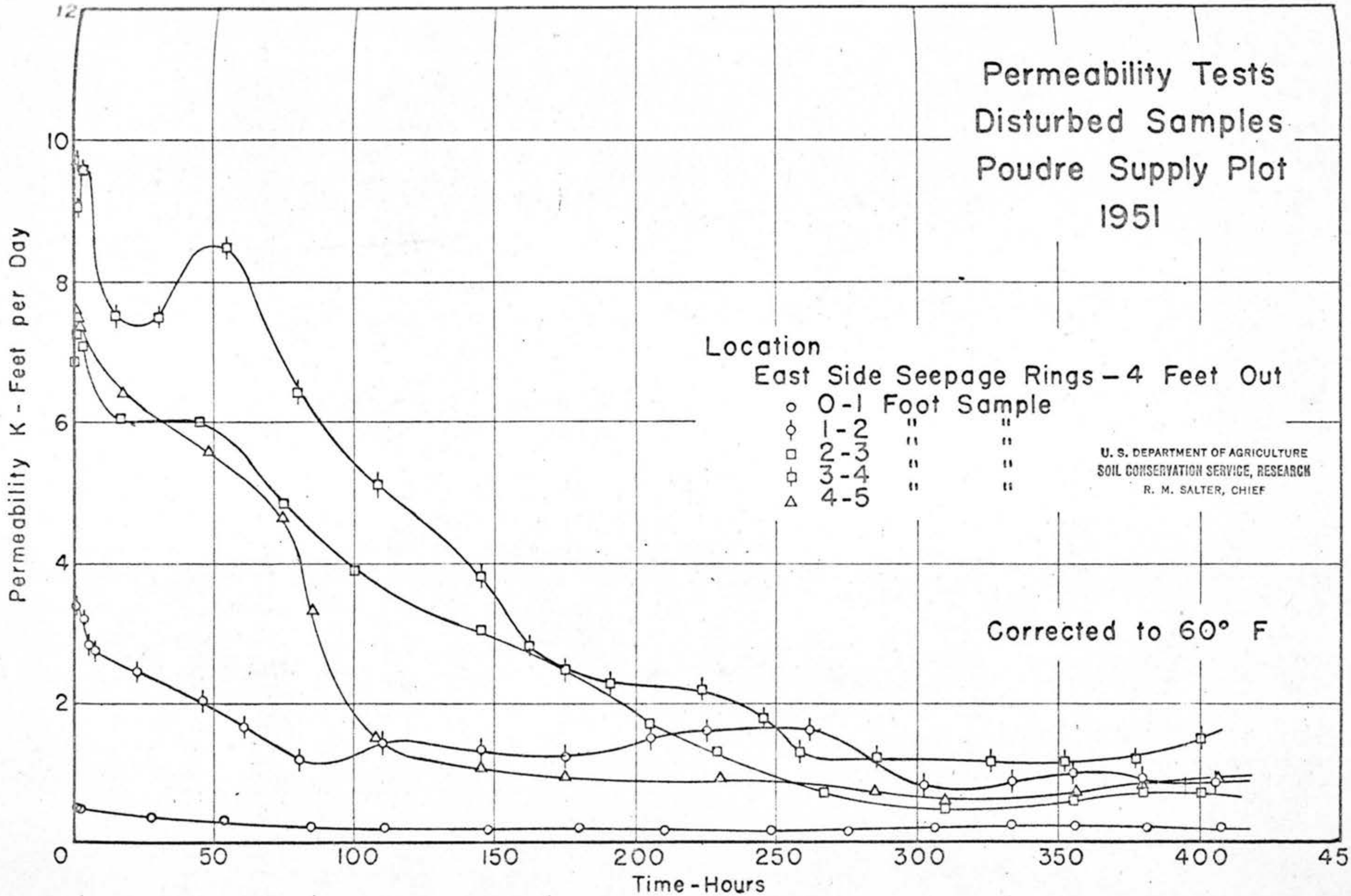
foot down to the limit of the sampling at 6.8 feet, a sandy loam is indicated. A silty clay existed for the upper two feet at the location on the west wide of the seepage rings with a sandy loam from 2 to 7.9 feet.

A chemical analysis of the soil is given in table 4. All the samples are alkaline in reaction except 7 and 8 which are weakly acid. There is not a significant amount of total soluble salt present in the samples and none contain an appreciable amount of gypsum. As would be expected, samples 1, 2 and 7, 8 which were taken near the surface, have the highest organic matter content. All the other samples are quite low in organic matter. Samples 4, 5, 6 and 12 have a high lime content.

An analysis of the water, which was taken from the Ft. Collins city water line, is given in table 1. This water contains a very low percentage of impurities and should have no effect on the seepage measurements.

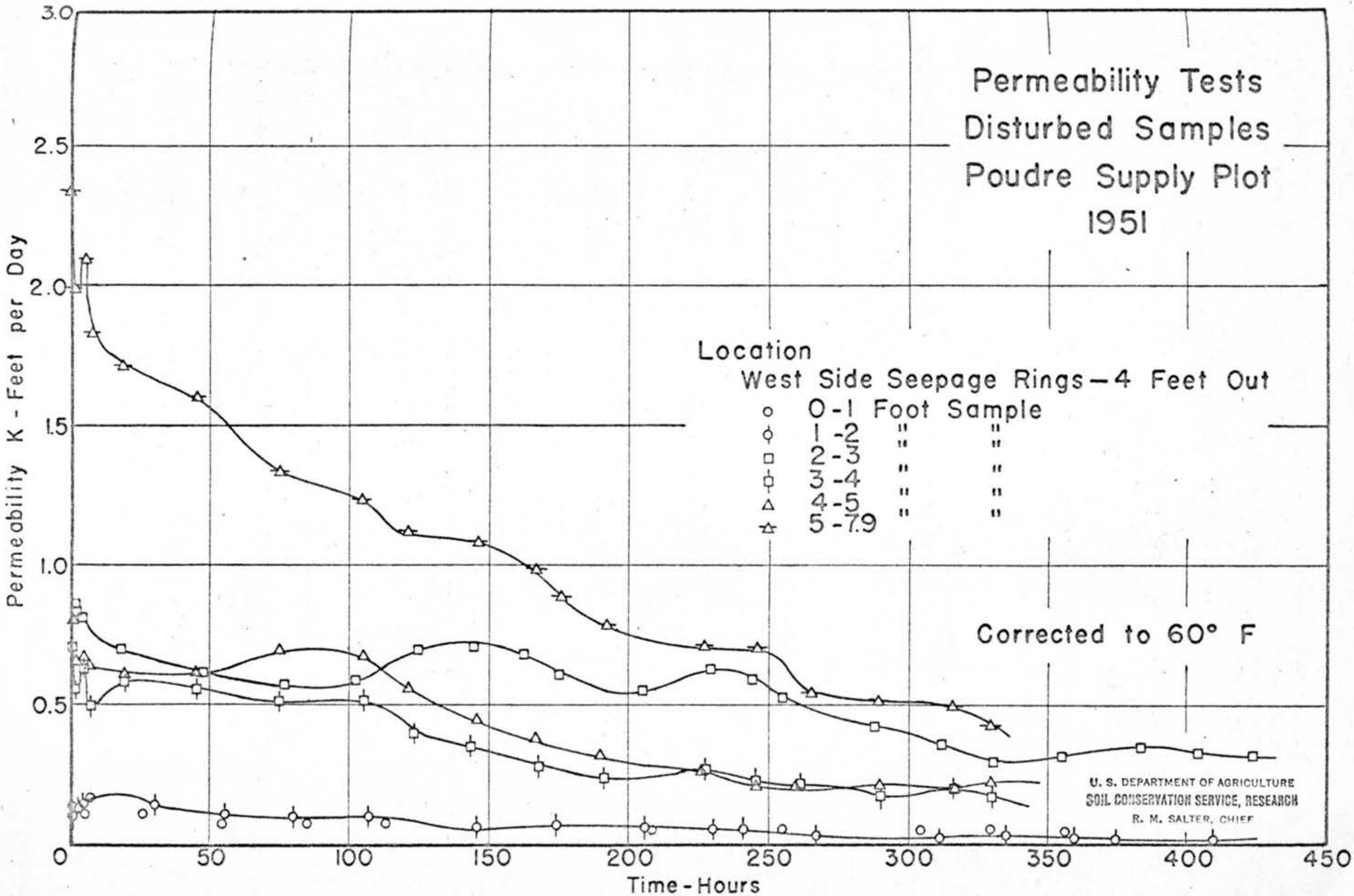
Permeameter tests of disturbed soil samples were run in the manner described in the 1950 progress report (10). Approximately 350 gms. per sample were dried then ground and passed through a 2-mm sieve. The sample was poured into a 2.5-inch (OD) lucite percolation cylinder from a height of 21 inches above the base using a funnel and rubber hose. For compaction the sample 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 (2). The actual tests, however, were made with the water percolating downward.

Percolation rates were obtained on duplicate samples for a period of from 15 to 17 days. Shown on figures 21 and 22 are the average computed permeabilities for the duplicate samples plotted against time. Generally, the rates for the samples taken on the west side of the rings were lower



Permeability Tests
Disturbed Samples
Poudre Supply Plot
1951
Location
East Side Seepage Rings — 4 Feet Out
0-1 Foot Sample
1-2 " "
2-3 " "
3-4 " "
4-5 " "
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, RESEARCH
R. M. SALTER, CHIEF
Corrected to 60° F
Permeability K - Feet per Day
Time - Hours
0
50
100
150
200
250
300
350
400
450
2
4
6
8
10
12

Figure 21



Permeability Tests
Disturbed Samples
Poudre Supply Plot
1951
Location
West Side Seepage Rings — 4 Feet Out
0-1 Foot Sample
1-2 " "
2-3 " "
3-4 " "
4-5 " "
5-7.9
Corrected to 60° F
Permeability K - Feet per Day
Time - Hours
3.0
2.5
2.0
1.5
1.0
0.5
0
50
100
150
200
250
300
350
400
450
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, RESEARCH
R. M. SALTER, CHIEF

Figure 22

than those from the east side. The permeability of the upper two feet on the west side is extremely low, about 0.04 foot per day. For the upper one foot on the east side the value of K was 0.20 foot per day. In either case the permeability increased with an increase in depth of sample. The permeabilities after fairly constant rates were maintained ranged from 0.20 to 1.20 feet per day for the east location and from 0.03 to 0.45 for the west location.

Seepage Rings - The Poudre Supply Plot is located on a corner of land owned by the U. S. Bureau of Reclamation at Station 226+00 of the Poudre Supply Canal. This location was chosen because of the existence of a fairly heavy clay and the availability of suitable water. The seepage rings, which had formerly been installed at the College Horticulture Plot, were moved and reinstalled at this location in the spring of 1951. Figure 23 shows the seepage rings and accessory equipment.

Water was first turned into the rings on June 19, 1951, and continuous tests were made until November 9 when the weather became too cold to continue. In addition to the customary readings, a record was kept of evaporation from a standard Weather Bureau Class A evaporation pan. Very soon after the rings started operating, difficulty was encountered in that the seepage rate from the inner ring was so low that the water meter ceased to function. This difficulty was overcome by filling the ring once each day and checking the seepage by noting the drop in the water surface. This same difficulty was encountered to a lesser degree in the outer ring after about two months of operation. From then on the water was allowed to run into the ring during the day but was cut off over night. The seepage during the night was determined from the drop in the water surface.

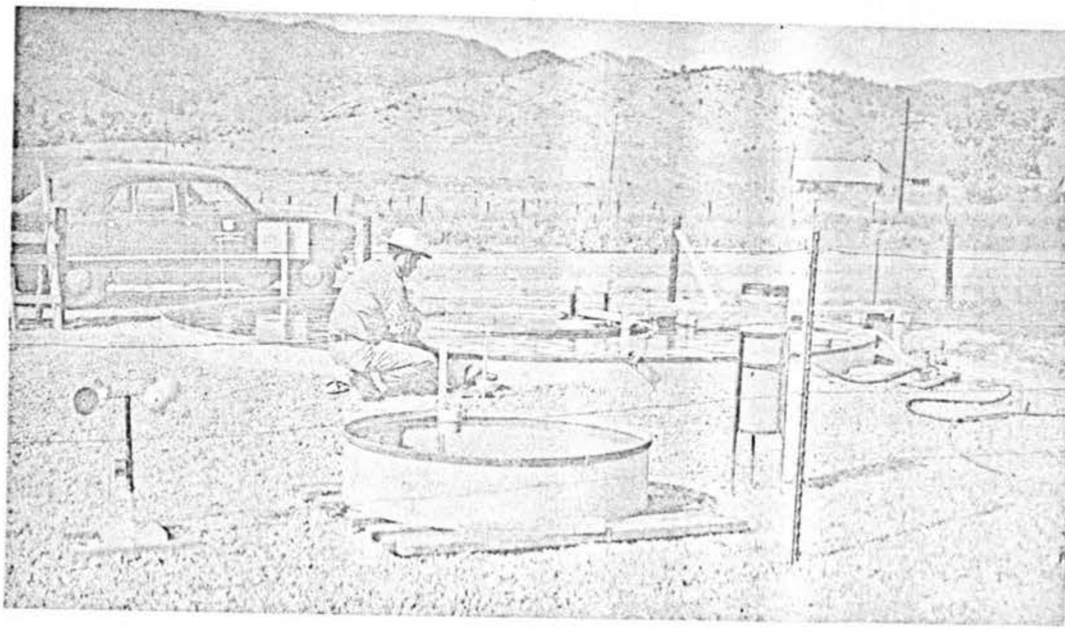


Figure 23.-- Seepage rings at Poudre Supply Plot with evaporation pan in foreground.

The observed seepage rates as well as data on water depths, water temperatures and barometric pressures are plotted on figure 24. The seepage rates were corrected for evaporation by applying a factor of 0.70 to the measured evaporation and then reducing the measured loss from the ring by this amount. From the very start the inner ring rate was very low, about 0.025 foot per day. This rate gradually increased for about three weeks until a maximum of 0.60 foot per day was reached. After that time, a gradual decrease is noted until a rate of almost zero was maintained. In fact, at times, it was almost impossible to separate the seepage and the evaporation. The rates from the outer ring were much larger, however. An initial daily rate of approximately 0.30 foot was maintained practically constant for a period of one month. After that time a fairly rapid decrease in rate is shown for about two weeks when the rate again became fairly constant at approximately 0.05 foot per day. There is a gradual decrease for the remainder of the period until at the end when a rate of 0.02 foot per day was reached. A sudden increase on October 22 is noted after a very cold period during which time there was a sharp decrease in the water temperature.

During August and again in October, tests were made to determine the effect of the depth of water in the rings on the seepage rate. Figures 25 and 26 are the results of these tests for the outer ring. The August determination shows rates which are much lower for the greater depths than the October test. However, the October test was made after an extremely cold period which seemed to have the effect of speeding up the seepage rate from the outer ring. According to the procedure previously described, a value of K for the August tests of 0.005 foot per day was found and a

Figure 24

Inches - Mercury
25.4
25.2
25.0
24.8
24.6
Barometric Pressure
Degrees F
80
70
60
50
40
Water Temperature
Seepage in Feet per Day
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Outer Ring Seepage
Inner Ring Seepage
Water Blown Out
Bottom of Rings Brushed
Ice on Water Surf.
Water Depth
Effect of Depth Test
Feet
2.0
1.5
1.0
0.5
0.0
Legend
□ Drop Test
○ S. C. S. Seepage Meter
△ U. S. B. R. Seepage Meter
Poudre Supply Plot
Seepage Rings
1951
June
July
August
September
October
November
20
30
10

Figure 25

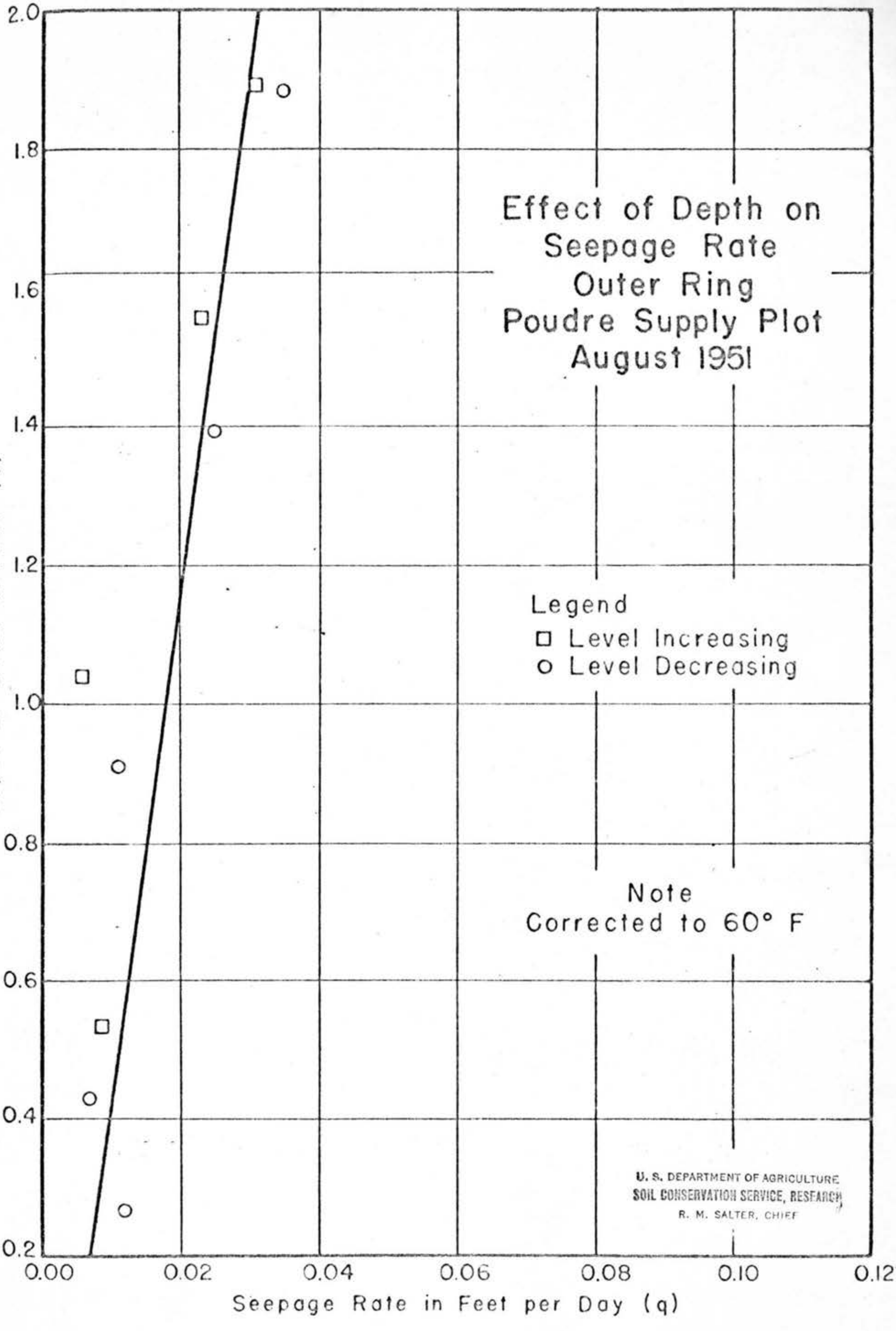

Effect of Depth on
Seepage Rate
Outer Ring
Poudre Supply Plot
August 1951
Legend
□ Level Increasing
o Level Decreasing
Note
Corrected to 60° F
Depth of Water in Feet (d)
Seepage Rate in Feet per Day (q)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.00
0.02
0.04
0.06
0.08
0.10
0.12
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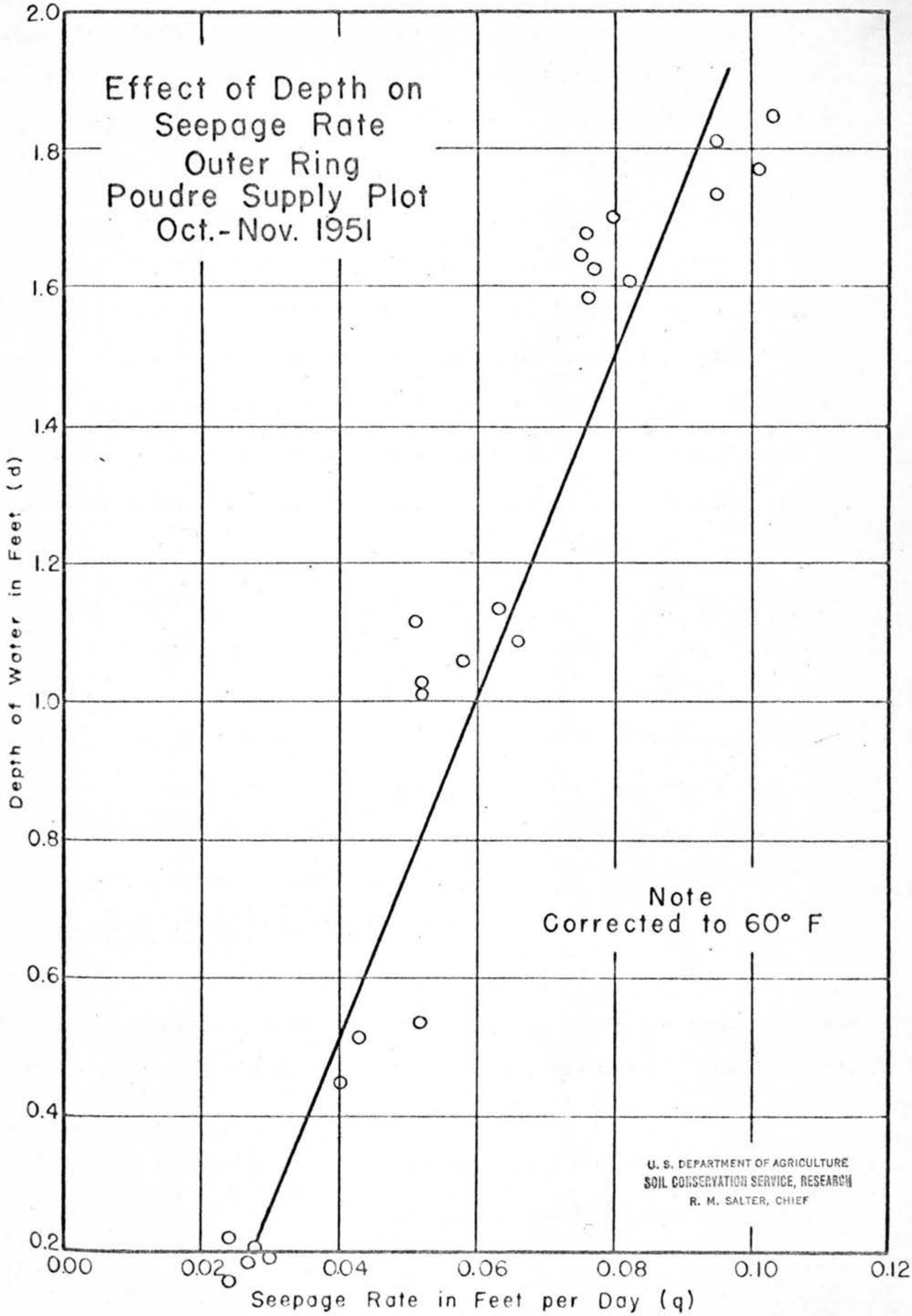
Figure 26


Effect of Depth on
Seepage Rate
Outer Ring
Poudre Supply Plot
Oct.-Nov. 1951
Depth of Water in Feet (d)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.00
0.02
0.04
0.06
0.08
0.10
0.12
Seepage Rate in Feet per Day (q)
Note
Corrected to 60° F
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value of 0.020 for the October test.

By using Glover's method (Equation 3) the computed permeability for the outer ring was 0.016 foot per day for the August test and 0.052 for the October test. In both cases the capillary tension was assumed to be zero and the soil saturated. Although the results computed by this method are of the same order of magnitude as those determined by the "Effect of Depth" tests the actual rates differ considerably. It should be kept in mind, however, that the rates are very small and it is probably not important whether the rate was 0.052 foot per day or 0.020 foot per day. Because of the extremely low seepage rate from the inner ring, the effect of depth tests gave erratic results. The unavoidable errors in the seepage and evaporation measurements were so large proportionately that they overshadowed the effect of depth.

Piezometers, approximately eight feet long, were installed at four locations ten feet out from the outer ring and another, one foot out. In addition, four piezometers 3, 4, 6 and 8 feet deep were placed in the inner ring. Weekly measurements were made of these piezometers. At no time during the season was free water apparent in the piezometers which indicated that the soil never became saturated.

Seepage Meter Tests - With the exception of the first series of tests with the SCS seepage meter which was made in the inner ring (location A), all the tests were conducted in the outer ring. Thirty two tests were made with the SCS meters and twenty seven with the USBR meters. These tests are shown plotted on figure 24 and are shown in tabular form in table 6. For location A, a rate much lower than the inner ring rate was initially observed. However, the rate kept increasing until a comparable rate was reached after

Table 6.-- Comparison of Seepage Ring and Seepage Meter Measurements of Seepage, Poudre Supply Plot.

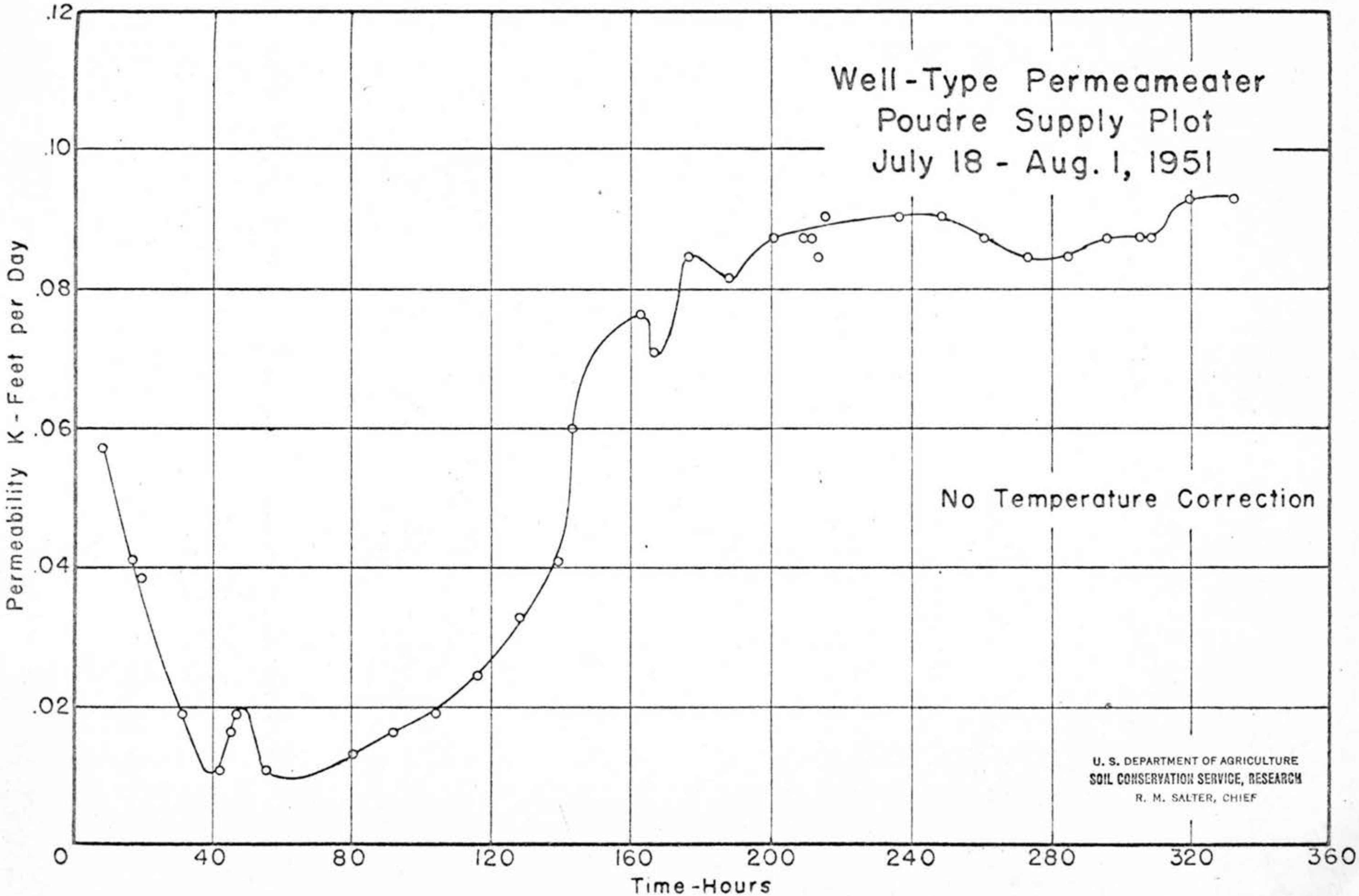
Time	Water	Seepage Rings		Seepage Meters			
		Inner Ring	Outer Ring	SCS		USBR	
	Depth	Rate	Rate	Loc.	Rate	Loc.	Rate
1951	Ft.	Ft/day	Ft/day		Ft/day		Ft/day
7-3	1.83	0.042	0.256	A	0.006	-	-
7-4	1.83	0.046	0.252	A	0.003	-	-
7-6	1.87	0.052	0.256	A	0.004	-	-
7-11	1.88	0.060	0.220	A	0.005	-	-
7-13	1.88	0.052	0.225	A	0.010	-	-
7-17	1.88	0.037	0.265	A	0.019	1	0.030
7-18	1.88	0.030	0.270	A	0.022	1	0.021
7-20	1.88	0.023	0.265	A	0.023	1	0.021
7-25	1.89	0.018	0.155	A	0.022	1	0.019
8-9	1.88	0.007	0.053	B	0.002	2	0.015
8-10	1.85	0.009	0.055	B	0.001	2	0.014
8-17	1.88	0.008	0.056	B	0.001	2	0.013
9-5	1.87	0.008	0.047	C	0.001	3	0.011
9-7	1.89	0.006	0.041	C	0.001	3	0.011
9-10	1.88	0.010	0.045	C	0.001	3	0.010
9-12	1.90	0.008	0.041	C	0.002	3	0.013
9-14	1.90	0.008	0.042	C	0.001	3	0.015
9-17	1.90	0.007	0.040	C	0.001	3	0.017
9-19	1.88	0.006	0.045	D	0.192	4	0.038
9-21	1.94	0.009	0.040	D	0.154	4	0.040
9-24	1.88	0.006	0.038	D	0.142	4	0.034
9-26	1.87	0.009	0.041	D	0.141	4	0.032
9-28	1.90	0.007	0.039	D	0.138	4	0.032
10-2	1.90	0.007	0.037	E	0.044	5	0.019
10-3	1.89	0.008	0.037	E	0.048	5	0.022
10-6	1.85	0.009	0.033	E	0.062	5	0.028
10-10	1.90	0.008	0.032	E	0.092	5	0.037
10-12	1.90	0.007	0.035	E	0.101	5	0.035
10-15	1.90	0.010	0.034	E	0.103	5	0.031
10-16	1.89	0.010	0.033	E	0.100	5	0.035
10-19	1.89	0.007	0.033	F	0.024	6	0.034
10-24	1.75	0.006	0.075	F	0.018	6	0.035

about two weeks. There is considerable variation between the rates as shown by the two methods. Wide variations in the soil in the outer ring no doubt caused large differences in the results because the seepage shown by the seepage meters would depend on the type of soil in which they were installed whereas the seepage for the outer ring was the average for all the types in the ring area.

Well-type Permeameter Tests - The well permeameter tests were made according to the procedure previously described. A total of eight tests was made at locations which completely encircles the seepage rings. These locations were approximately ten feet out from the outer ring. Each hole was about 18 inches deep with the water being held at about one foot in depth. Figures 27, 28, 29 and 30 are plots of representative tests. These tests show a five-fold variation in the final value of the permeability, 0.09 to 0.50 foot per day. Some of these tests acted in a very erratic manner as is seen in figure 27. For this test an initial rate of 0.057 foot per day is shown followed by a sharp decrease to about 0.010. After this point there is a steady increase until the rate leveled off at 0.09 foot per day. Here also, the large differences in the results of the different tests can be explained by differences in the soil at the various locations.

Poudre Supply Canal Seepage Tests

The first release of water from Horsetooth Reservoir of the Colorado Big Thompson Project was made in July 1951. This water is carried by the Poudre Supply Canal to the Poudre River. Because of changes in grade when emerging from a lined into an unlined section and from the unlined back to a lined section, a natural pool was formed between Stations 167+50 and 186+00 when the water was cut off. This pool averaged about 1.5 feet deep when



Well-Type Permeameater
Poudre Supply Plot
July 18 - Aug. 1, 1951
No Temperature Correction
Permeability K - Feet per Day
.12
.10
.08
.06
.04
.02
0
40
80
120
160
200
240
280
320
360
Time-Hours
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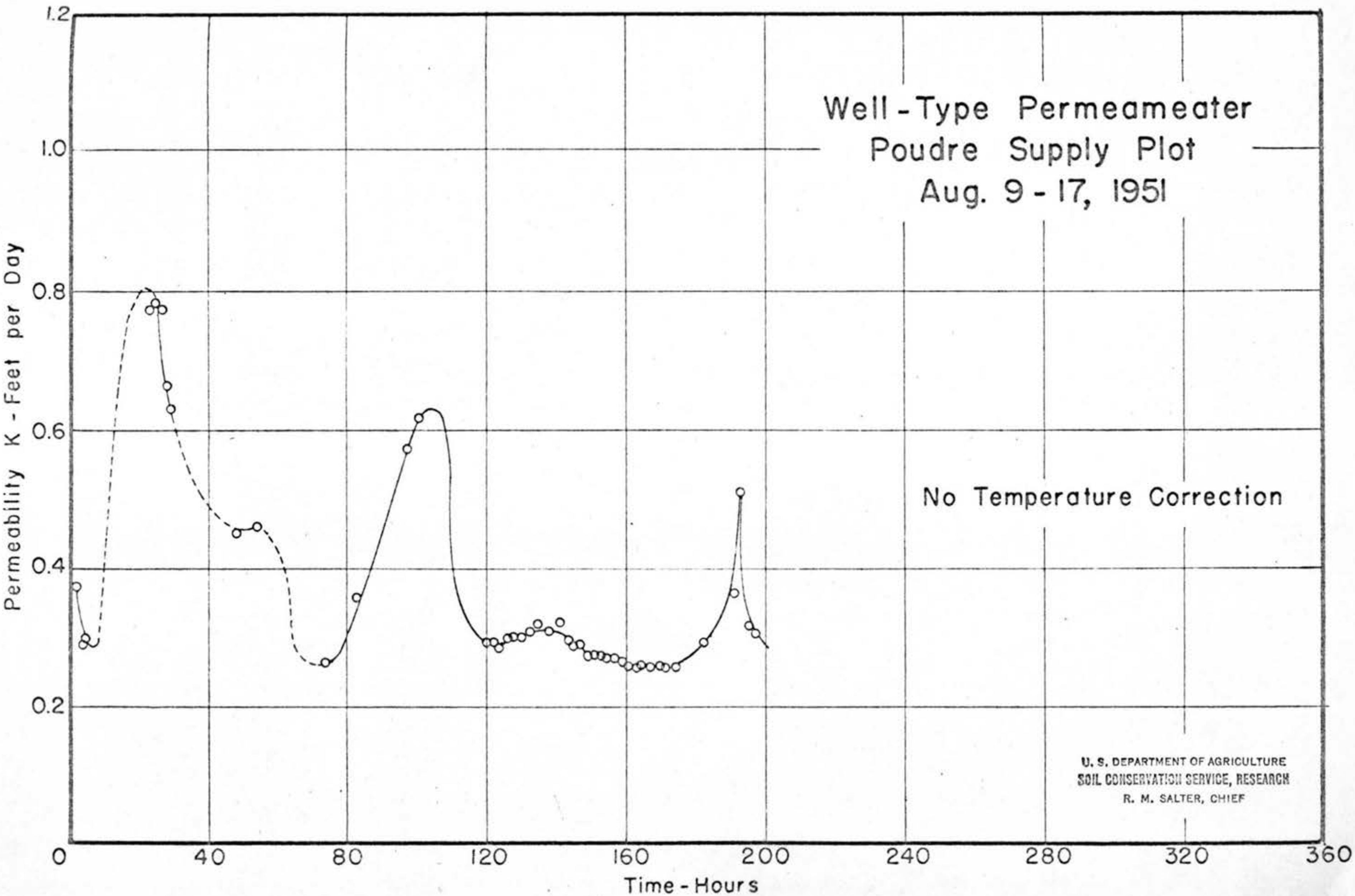
Figure 27



Well-Type Permeameater
Poudre Supply Plot
Aug. 9 - 17, 1951
No Temperature Correction
Permeability K - Feet per Day
Time - Hours
1.2
1.0
0.8
0.6
0.4
0.2
0
40
80
120
160
200
240
280
320
360
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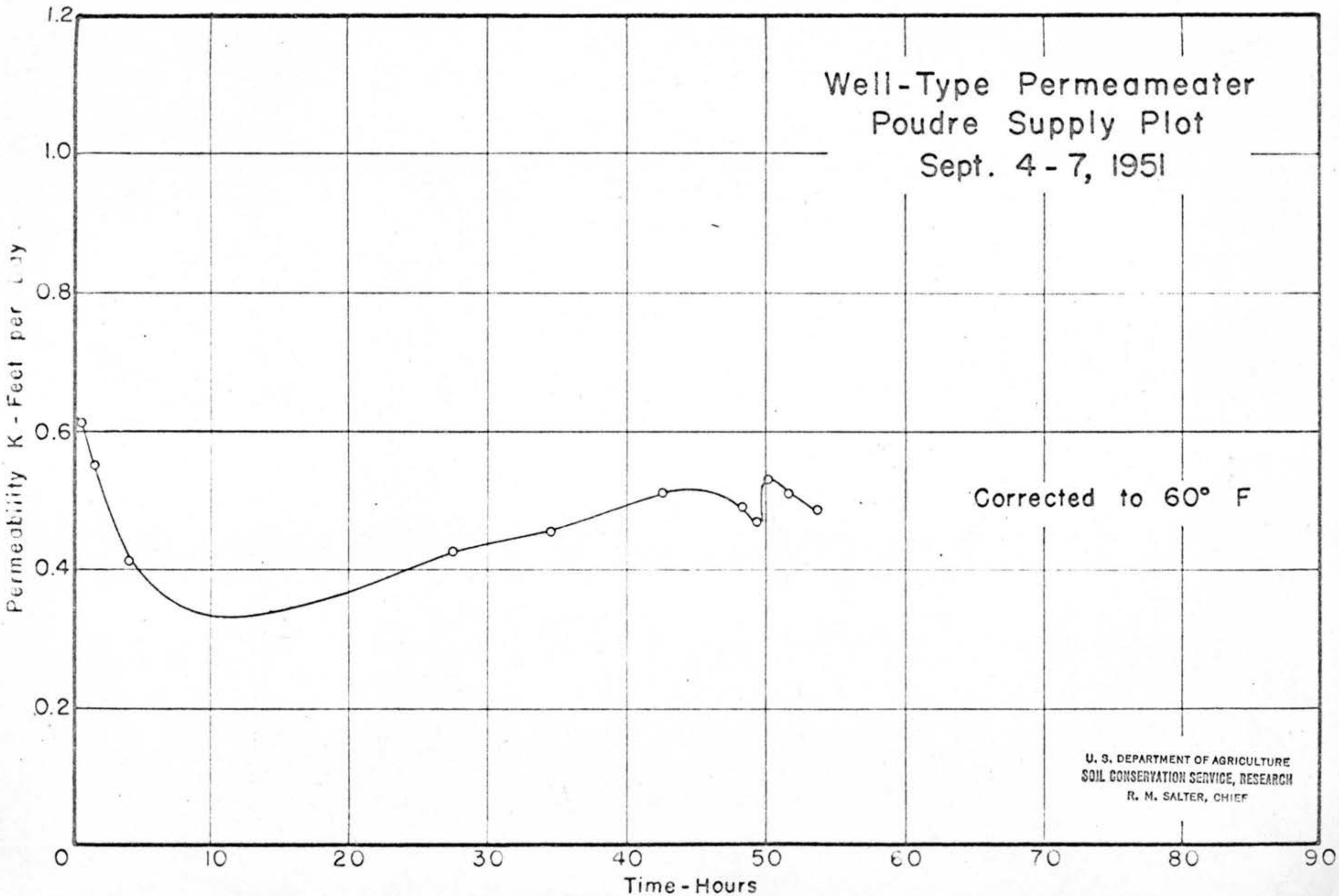
Figure 28



Well-Type Permeameater
Poudre Supply Plot
Sept. 4-7, 1951
Corrected to 60° F
Permeability K - Feet per Day
Time-Hours
0
10
20
30
40
50
60
70
80
90
0.2
0.4
0.6
0.8
1.0
1.2
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Figure 29

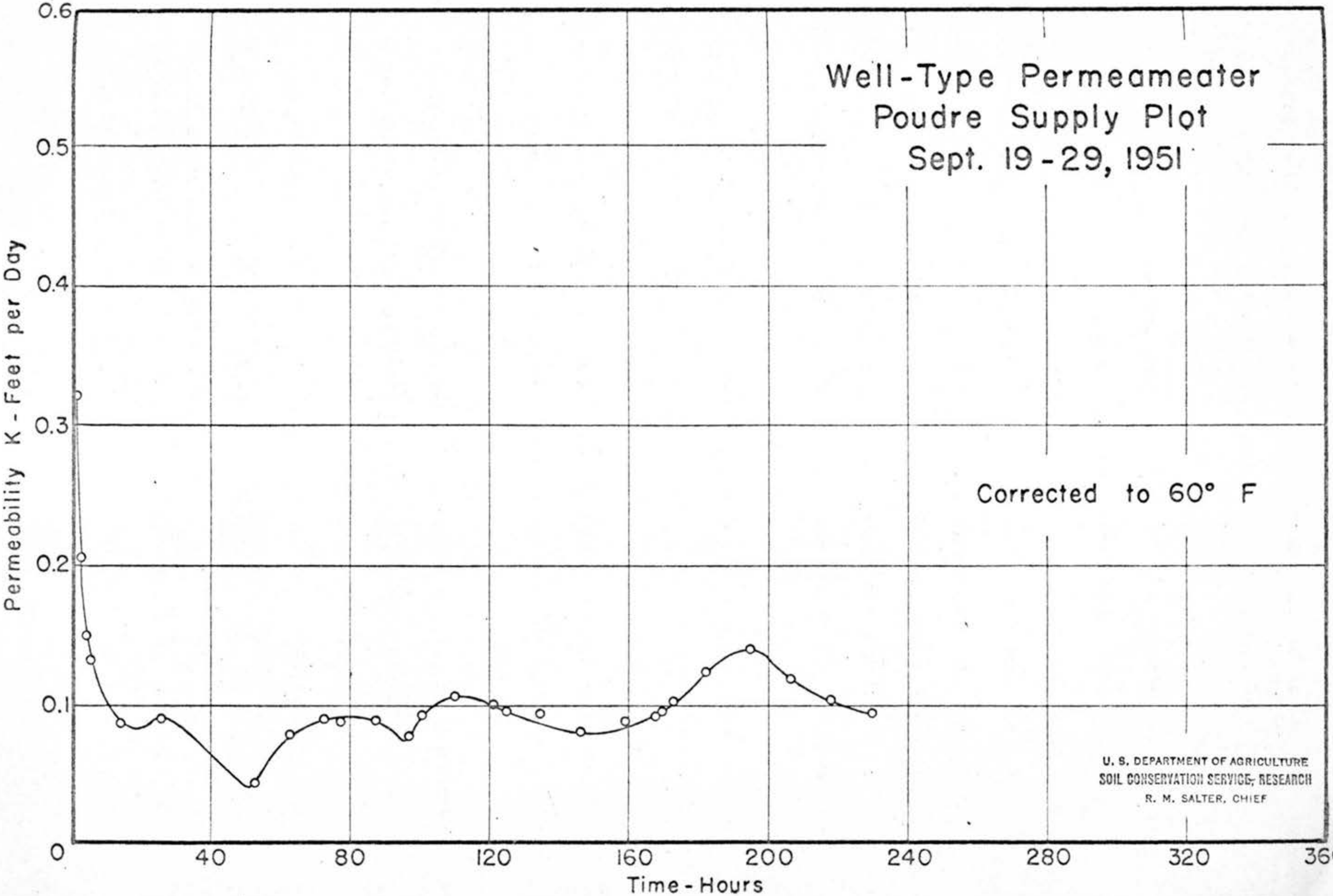
Well-Type Permeameater
Poudre Supply Plot
Sept. 19-29, 1951
Corrected to 60° F
Permeability K - Feet per Day
Time - Hours
0.6
0.5
0.4
0.3
0.2
0.1
0
40
80
120
160
200
240
280
320
360
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Figure 30

water stopped running from the section. Tests were made of the seepage in July and again in August after the pool had been refilled by an unusually heavy rain.

Ponding Tests - Since the pool used for the measurements was 1850 feet long it was necessary to mount a staff gage at each end. This was done so that the effect of the wind piling the water up on either end could be compensated for. The results of these tests, table 7, show that the rates obtained during the first pool filling were considerably higher than those obtained at the second filling. It should be pointed out that the first test was also the first time that water had been in the canal. The second test, where the rate was only one-fourth that for the first test, was made after flooding had filled the pool with heavily silt-laden water.

Seepage Meter Tests - Seepage meter tests were conducted at the same time that the first ponding test was being made. Both the SCS and the USBR type seepage meters were used with installation being made together near the center line of the Canal. Some difficulty was encountered in setting the meters because of the existence of bed rock along the bottom in part of the section. Because of shallow water it was impossible to set the meters on the side-slopes of the canal. Table 8 gives the results of these tests. Except for the installation at Station 181+54, the rates are all considerably below those for ponding. The seepage from the sides of the canal was probably much greater than the bottom because of the stratification of the soil.

North Poudre Supply Canal Seepage Tests

At the request of the U. S. Bureau of Reclamation, the Division of Irrigation Engineering cooperated with Chester W. Jones of the Bureau in

Table 7.-- Pool Measurement of Canal Seepage,

Poudre Supply Canal - Sta. 167+50 - 186+00.

Date	Time	Depth Water	Average Wetted Perimeter	Average Width	Drop for Period	Evaporation for Period	Corrected Drop	Length of Period	Drop	Seepage
1951		Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Days	Ft/day	Ft/day
7-25	9:40A	1.71	38.2	37.1						
7-25	4:55P	1.60	37.8	36.8	0.110	0.016	0.094	0.302	0.312	0.303
7-26	9:20A	1.41	37.1	36.2	0.190	0.014	0.176	0.684	0.258	0.252
7-26	4:10P	1.32	36.8	36.0	0.090	0.014	0.076	0.284	0.267	0.260
7-27	8:45A	1.14	36.1	35.4	0.180	0.010	0.170	0.690	0.246	0.241
7-27	4:20P	1.06	35.8	35.2	0.080	0.007	0.073	0.316	0.231	0.227
7-28	9:35A	0.92	35.3	34.8	0.140	0.007	0.133	0.719	0.185	0.182
7-28	5:25P	0.84	35.0	34.5	0.080	0.014	0.066	0.326	0.202	0.199
7-29	9:30A	0.71	34.5	34.1	0.130	0.009	0.121	0.670	0.180	0.178
7-29	6:45P	0.64	34.3	33.9	0.070	0.011	0.059	0.385	0.153	0.151
7-30	9:35A	0.54	33.9	33.6	0.100	0.006	0.094	0.618	0.152	0.150
7-30	4:05P	0.49	33.7	33.5	0.050	0.008	0.042	0.270	0.156	0.155
7-31	9:15A	0.39	33.4	33.2	0.100	0.010	0.090	0.715	0.126	0.125
7-31	4:15P	0.34	33.2	33.0	0.050	0.008	0.042	0.291	0.144	0.143
8-1	9:10A	0.26	32.9	32.8	0.080	0.012	0.068	0.705	0.096	0.095
					Pool Refilled by Flood					
8-8	4:10P	1.66	38.0	37.0						
8-9	4:20P	1.56	37.6	36.7	0.100	0.022	0.078	1.01	0.077	0.075
8-10	4:20P	1.47	37.3	36.4	0.090	0.016	0.074	1.00	0.074	0.072
8-12	5:20P	1.30	36.7	35.9	0.170	0.042	0.128	2.04	0.063	0.062
8-14	6:10P	1.10	35.8	35.3	0.200	0.038	0.162	2.03	0.080	0.079

Table 8.-- Seepage Meter Measurement of Canal Seepage,

Poudre Supply Canal - Sta. 167+50 - 186+00.

Date 1951	Station	Seepage Meter Type	Seepage Rate Ft/day
7-27	172+30	USBR	0.005
7-27	172+30	SCS	0.004
7-25	174+31	USBR	0.006
7-26	174+31	USBR	0.007
7-25	174+28	SCS	0.009
7-26	174+28	SCS	0.005
7-26	177+79	USBR	0.038
7-27	177+79	USBR	0.023
7-26	177+76	SCS	0.001
7-27	177+76	SCS	0.001
7-24	181+55	USBR	0.149
7-25	181+55	USBR	0.139
7-24	181+54	SCS	0.109
7-25	181+54	SCS	0.098
7-27	183+78	USBR	0.000
7-27	183+78	SCS	0.004

making a series of well permeameter tests along the center line of an unlined section of the proposed North Poudre Supply Canal of the Colorado Big Thompson Project. Observations were made on five locations between Stations 245+45 and 257+90. The equipment at one of the locations is shown in figure 31. Soil samples were also taken at various points along the reach. Results of the soil analyses are shown in table 9. This analysis shows that the soil varied from silt and silty clay to poorly graded sand near the north end of the reach.

The permeameter tests were made with holes about 6 inches in diameter and depths varying according to the amount of excavation at that point. Observations were carried on day and night for a week during the month of May. Figures 32, 33, 34 and 35 are plots of the results. The tests at Stations 246+48 and 254+76 were continued for a much longer period than the others. A study of these plots indicates that the permeability K probably ranges between 0.20 and 0.30 foot per day after a test period of about 5 days. This value of permeability may be used in the equation developed by Muskat (6), which is:

$$Q = \frac{K\ (B+2H)}{WP} \tag{4}$$

where

Q = The seepage in cubic feet per square foot of area per day.

K = The permeability determined by the well permeameter test in feet per day.

B = Width of water surface in the canal.

H = Depth of water in the canal.

WP = Wetted perimeter of the canal.

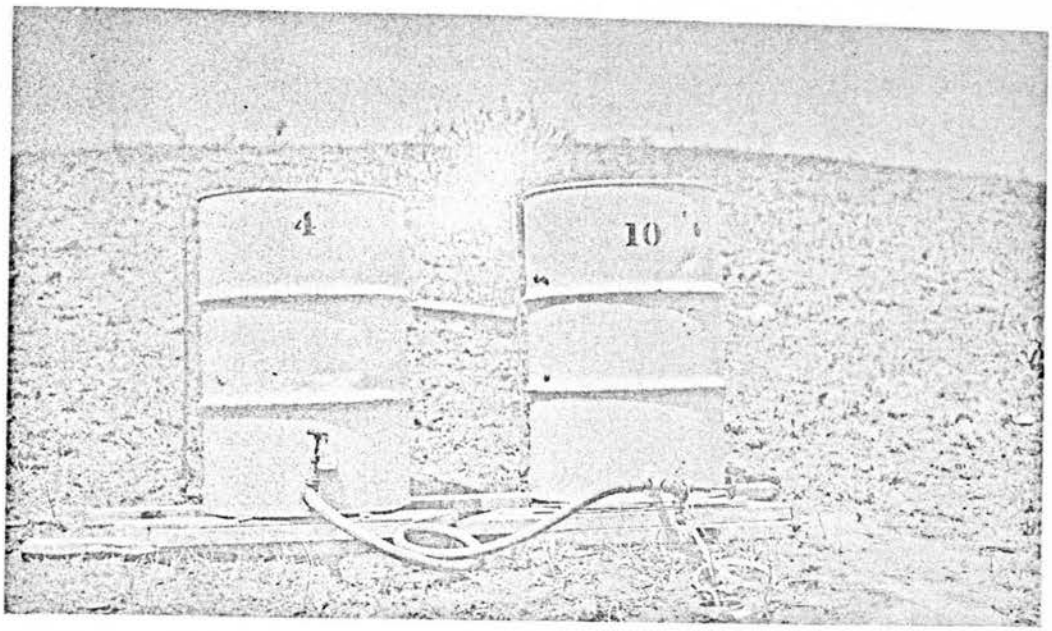

Figure 31.-- Equipment for well permeameter test, North Poudre Supply Canal.

Table 9.-- Soil Analysis,
North Poudre Supply Canal.
(Classification by Bureau of Reclamation)

Station	Depth of Sample	Classification (Adapted from (A.C.) system by Casagrande)
246+35	0.0- 1.0	SILT--Some clay. Presence of roots. Dark brown color (topsoil)
	2.0- 3.0	CLAY, LEAN--Moderately plastic. Slightly silty. No sand. Dark brown
	3.0- 4.0	SILT--Light brown
	4.0- 8.0	SILT--Trace of clay. Medium brown
	8.0-12.0	SILT--Trace of clay. Some very fine sand. Medium brown
248+48	0.0-13.0	SILT--Trace of clay. Reddish brown
248+55	0.0- 3.0	CLAY, LEAN--Slightly plastic. Very silty. Dark brown (topsoil)
	3.0- 5.7	SILT--Medium brown
250+80	1.0- 2.0	SILT--Trace of clay. Medium brown
	2.0- 5.0	SILT--Medium brown
	5.0-15.0	SILT--Some fine sand. Medium brown
	15.0-16.0	SAND WITH EXCESS SILT--Sand fine to medium. Very silty. About 10 percent gravel, maximum size 1 inch.
	16.0-17.0	SILT--Trace of clay. Light brown.
254+73	1.0- 7.0	SILT--Trace of fine sand. Medium brown
265+65	2.0- 4.0	SILT--Trace of clay and organic matter. Dark brown
	4.0- 7.0	SAND WITH EXCESS SILT--Sand fine. Very silty. Medium brown
	7.0- 8.0	SAND POORLY GRADED--Sand predominatly fine. Silty. Trace of coarse sand and gravel, maximum size 3/4 inch. Medium brown
	8.0- 9.0	SAND POORLY GRADED--Sand predominatly fine. Some medium to coarse. About 25 percent gravel, maximum size 2 inches
256+86	0.0- 2.0	SILT--Trace of clay and organic matter (topsoil). Dark brown

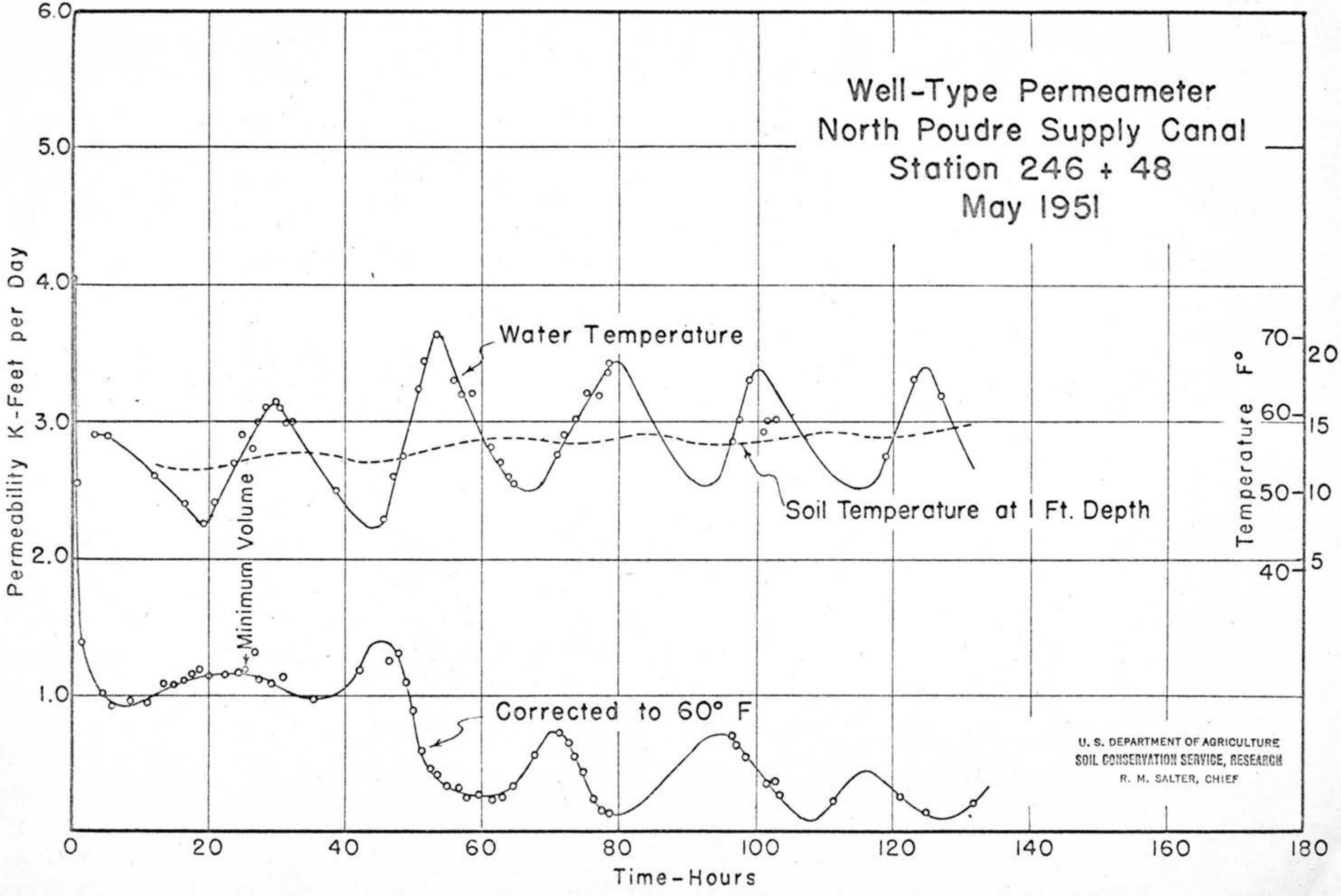
Well-Type Permeameter
North Poudre Supply Canal
Station 246 + 48
May 1951
Water Temperature
Soil Temperature at 1 Ft. Depth
Minimum Volume
Corrected to 60° F
Permeability K-Feet per Day
Temperature F°
Temperature C°
Time-Hours
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Figure 32

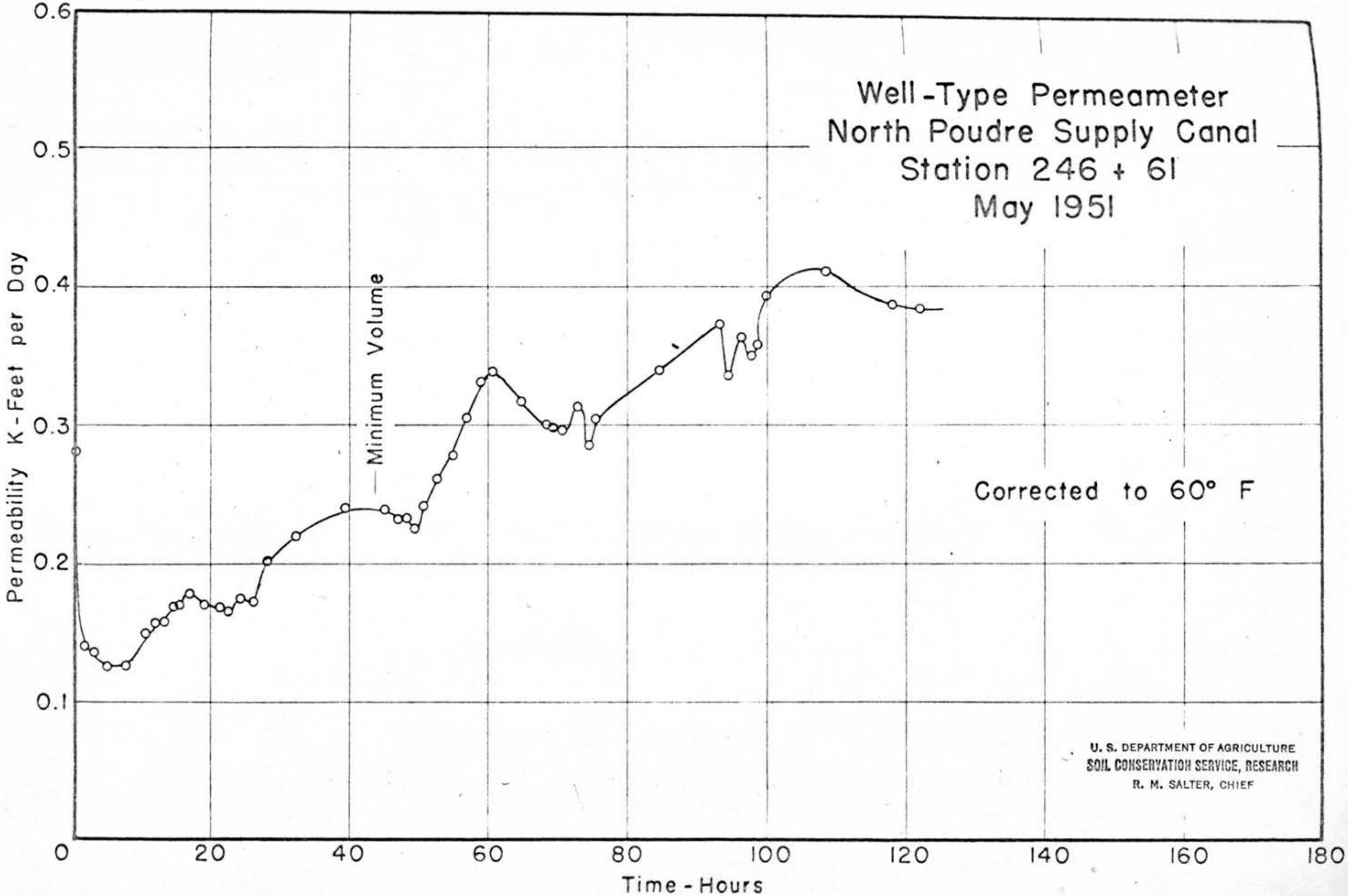
Well-Type Permeameter
North Poudre Supply Canal
Station 246 + 61
May 1951
Corrected to 60° F
Minimum Volume
Permeability K-Feet per Day
Time - Hours
0.6
0.5
0.4
0.3
0.2
0.1
0
20
40
60
80
100
120
140
160
180
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Figure 33

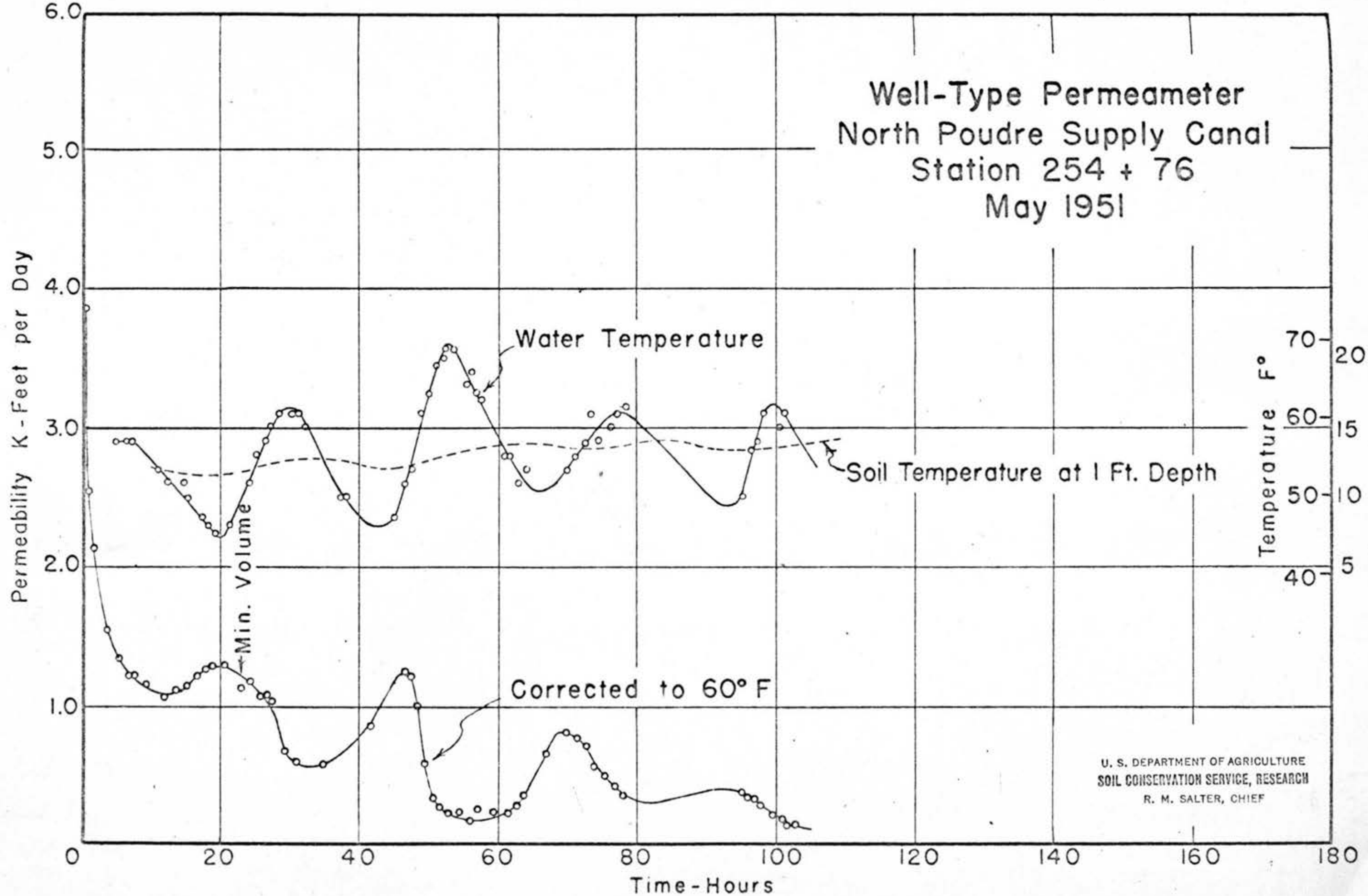
Well-Type Permeameter
North Poudre Supply Canal
Station 254 + 76
May 1951
Permeability K - Feet per Day
Time - Hours
Temperature F°
Temperature C°
Water Temperature
Soil Temperature at 1 Ft. Depth
Corrected to 60° F
Min. Volume
6.0
5.0
4.0
3.0
2.0
1.0
0
20
40
60
80
100
120
140
160
180
70
60
50
40
20
15
10
5
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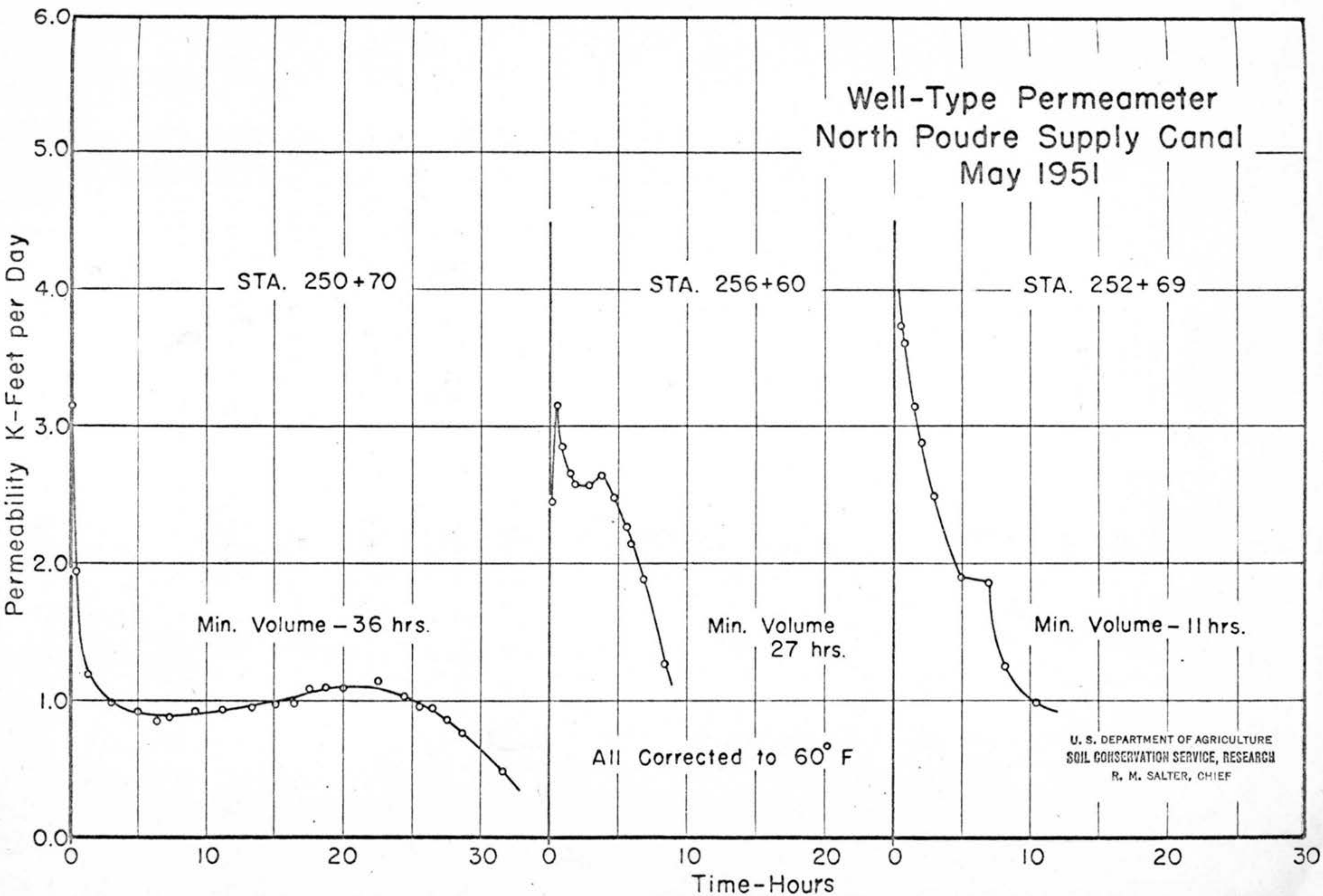
Figure 34



Well-Type Permeameter
North Poudre Supply Canal
May 1951
STA. 250+70
STA. 256+60
STA. 252+69
Min. Volume – 36 hrs.
Min. Volume 27 hrs.
Min. Volume – 11 hrs.
All Corrected to 60° F
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Permeability K-Feet per Day
Time-Hours
0.0
1.0
2.0
3.0
4.0
5.0
6.0
0
10
20
30

Figure 35

Solving this equation between the two limits of permeability gives values for the actual seepage loss from the canal as ranging from 0.24 to 0.36 cubic foot per square foot per day. This value will be checked by a ponding test after excavation of the canal has been completed.

A daily variation in the permeability is indicated on figures 32 and 34. This same occurrence was noted for the seepage rings at Bellvue when readings were taken continuously over a period of several days. This variation is not caused by the actual difference in the temperature of the water because the variation in the rate is still apparent after all the temperatures were reduced to 60° Fahrenheit. The variation may however, be due to the difference between the temperature of the water and of the soil. If the water became colder as it percolated through the soil, air would be absorbed and consequently the seepage rate would increase. If the water was warmed by the soil the seepage rate would be decreased. The significant feature is the direction of the temperature gradient. Since this fact was not recognized at the time the observations were being taken, no attempt was made to measure the soil temperatures and consequently there is no way of knowing what the actual temperature gradients were.

Arthur Ditch Seepage Measurements

During the 1950 testing season several inflow-outflow measurements were made on a 1925 foot reach of the Arthur Ditch which flows through the College Campus along the south side of the Horticulture Plot. The measurements which were made with a current meter, gave fairly consistent percentages of seepage loss from the section. In 1951 inflow-outflow measurements were again made using the same method at the same measuring sections. At this time practically every determination showed a gain in the section. A close inspection of the reach showed that there was no apparent side inflow within the section. These results confirm the conclusion previously reached that the normal error in current meter measurements may be greater than the seepage losses.

DISCUSSION OF RESULTS

Although the seepage rings at the Bellvue Laboratory had been operated for several months the previous season, the seepage rate continued to decline during the period the tests were conducted in 1951. This indicates that the length of time that water has been in a canal is probably one of the most important factors in determining seepage losses. (See figure 36). At Bellvue the initial seepage rate for the 1951 season was practically the same as the end rate for the previous season. At the end of the 1951 season the rate was only 1/4 that of the previous season. For the Horticulture Plot seepage rings, the seepage rates after the initial high were considerably lower during the second season of operation. In both cases, the water was free of sediment and the chemical composition was such that neither of these items would, in itself, affect the permeabilities of the soils. The decrease in seepage then must be a result of micro-biological action (1), the breaking down of the soil particles, and possibly other factors not determined.

The seepage rings at the Poudre Supply Plot, although operated for only one season also showed a marked decrease in seepage over the period. This installation demonstrated the large range of permeabilities that may be encountered in even small areas. Although the site was investigated and thought to be fairly uniform before the location of the seepage rings, it was found after operation that the soil on one side of the outer ring was several times more permeable than on the other side. The inner ring, however, covered an area of uniform permeability.

The observations on the effect of depth on the seepage again demonstrated the fact that the rate of seepage is not directly proportional to

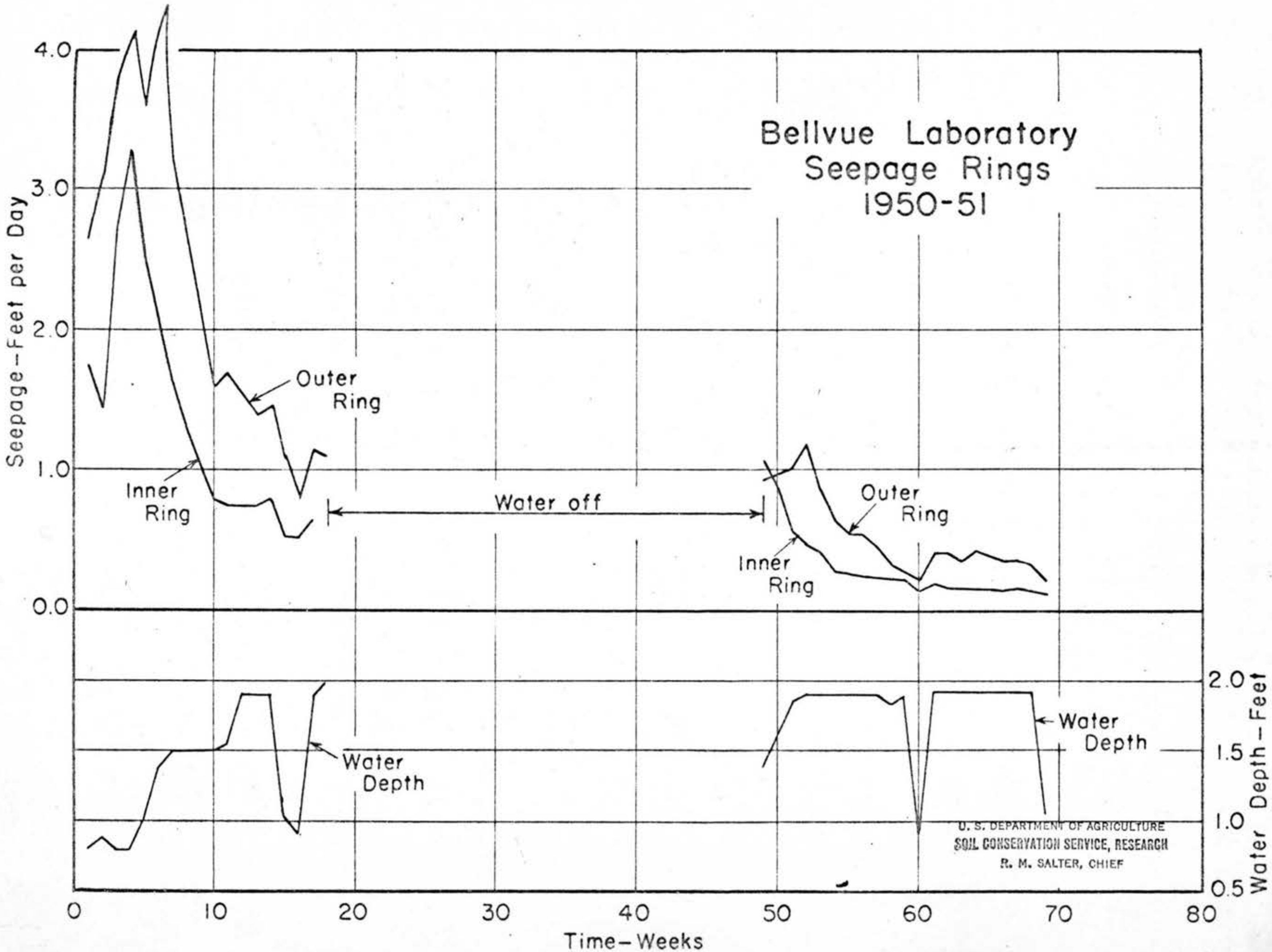
Bellvue Laboratory
Seepage Rings
1950-51
Seepage-Feet per Day
4.0
3.0
2.0
1.0
0.0
Outer
Ring
Inner
Ring
Water off
Outer
Ring
Inner
Ring
Water
Depth
Water
Depth
2.0
1.5
1.0
0.5
Water Depth - Feet
0
10
20
30
40
50
60
70
80
Time-Weeks
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Figure 36

the depth of water above the ground surface but is proportional to the depth plus some distance below the surface. According to Israelson (5) the head resulting from the depth of water is used up within the upper few inches of the soil. If this is the case, only a small error would be incurred in assuming that the seepage rate varied directly with the water depth provided the depth was fairly great. The tests on the effect of depth at the Horticulture, Bellvue and Poudre Supply sites indicate that from several inches to a foot of soil may be required to use up the head available from the water. The more permeable the soil the longer the column of soil that is required. The two tests at the Bellvue plot showed that the effect of depth was fairly constant, whereas the tests at the Poudre Supply Plot varied widely.

The results of permeability determinations using the "Effect of Depth" tests and the method developed by Glover show a very close correlation for the Bellvue tests. However, there is a fairly large divergence in the results of the two methods for the Poudre Supply Plot. At each location the capillary tension was assumed to be zero. It is possible that a tension did exist at the Poudre Supply Plot which might be a reason for the large percentage difference in the results at that location.

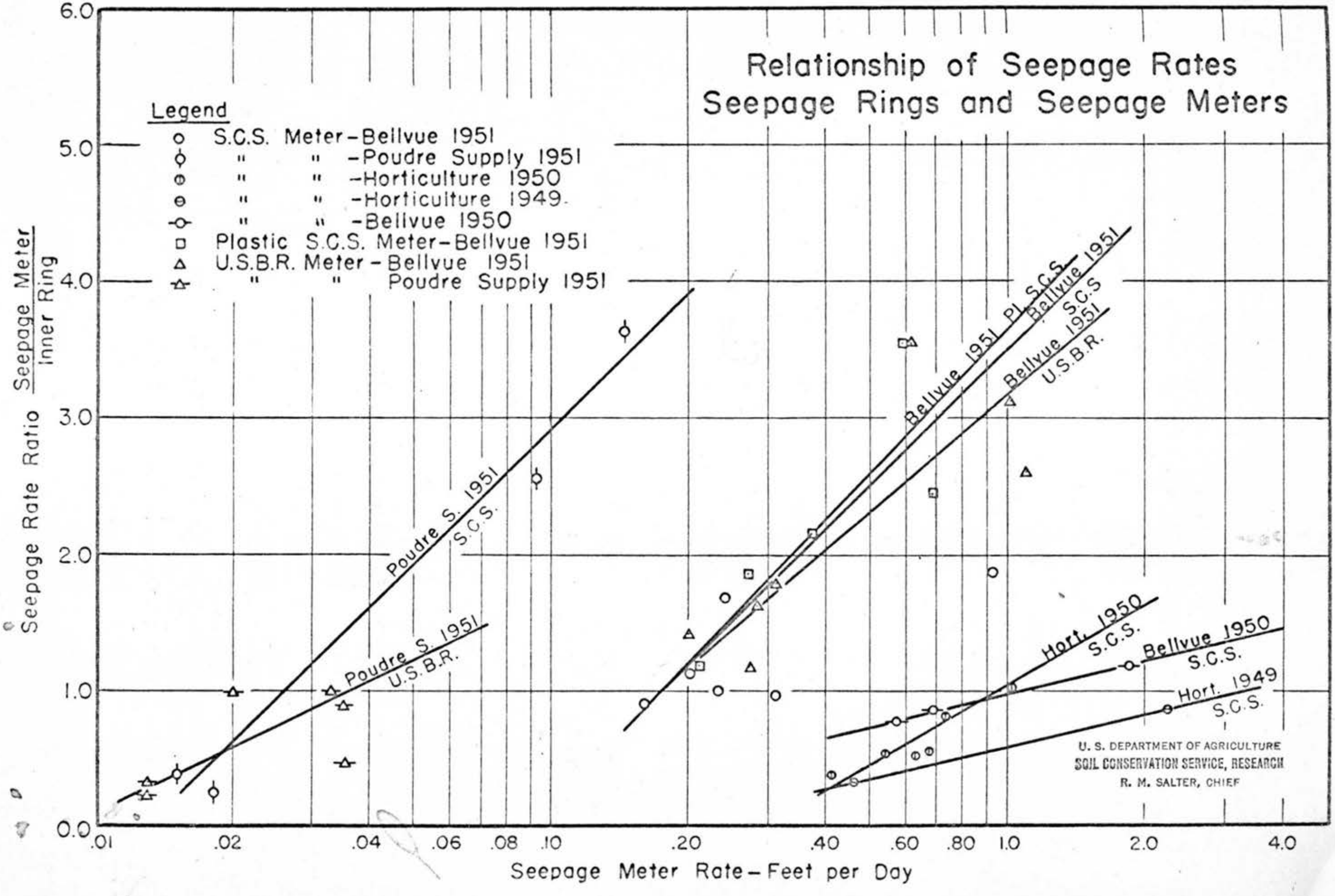
On one occasion, after an effect of depth test at Bellvue the seepage rate increased over that which it had originally shown for the same depth. The increased head probably temporarily opened enterstices in the soil which gradually became clogged again.

It was noted at Bellvue that there seemed to be an hourly fluctuation in the seepage rates. Investigation showed that there was a variation even after correcting for the difference in viscosities as a result of temperature changes. Continuous readings, night and day, over a period of several days were made to check this variation. The results, figure 13, seem to indicate that the fluctuations which were as much as 50 percent, might be due to the relationship of the water and soil temperatures and the amount of trapped air (2). Similar observations on the inner and outer rings of the Poudre Supply site were inconclusive because the losses were so small that the errors in the readings and in the evaporation correction obscured any effect that temperature relations might have on the results. Further study of this phenomenon is planned for the coming season. It was also noted that the seepage rate of the outer ring at the Poudre Supply Plot speeded up materially after a period in October when the temperature of the water approached freezing. One explanation of this could be that microbiological action slowed down or ceased because of the low temperature, thereby causing the increased rate.

Although water was being fed into the soil continuously at the maximum rate, there was no effect on the position of the water table in the vicinity of the seepage rings. The ground water levels at Bellvue as observed with piezometers are shown in figure 14. This shows that the only apparent fluctuation was due to the change of stage of the Poudre River nearby. The indications are that the seepage rate was controlled at or near the surface and regions of increasing permeability existed down to the water table. At the Poudre Supply plot, water was never apparent in the piezometers, indicating that a saturated zone under the rings never existed. Here again, the amount of seepage was probably governed at the surface.

Since it had been pointed out that the method of installing seepage meters (8) might affect the results obtained, great care was exercised in installing the meters. Hammering on the meter probably puddles the soil and reduces the permeability. All the installations during 1951 were made by standing on the meter or by jacking using an anchor and lever. Two types of the SCS meters as well as the USBR type plastic bag seepage meter, were used. Tables 2 and 6 are compilations of the seepage meter data taken during the 1951 season within the seepage rings and also show the seepage ring rates at a comparable time. No general trends of the rates can be seen as was the case of the tests at the Horticulture plot in 1950 (7). Here the seepage meter showed a high rate soon after installation which decreased along a smooth curve until the end rate was generally below that shown for the rings. At Bellvue in the sandy loam the seepage meters usually gave rates above those shown for the inner ring, but less than the rate for the outer ring. The seepage meter rates at the Poudre Supply plot in heavy clay were generally below those determined for the outer ring and less than the rate for the inner ring. In the study made at the University of Idaho (11), the seepage meter always gave rates which were less than those shown by a seepage ring in either clay, silt or sand.

In an attempt to develop a calibration curve for the seepage meters, figure 37 was prepared. This figure shows the correction factors that should be applied to the seepage meter readings in order to give the same rate as the seepage ring. The meter was usually installed and left in place for periods of from one to two weeks and readings were made beginning on the day of installation and each second day thereafter. The data shown represent an average of the rates disregarding those made within two days of installation which should eliminate those readings that might be affected by the initial disturbance caused by installing the meter. Figure 37 shows



Relationship of Seepage Rates
Seepage Rings and Seepage Meters
Legend
S.C.S. Meter-Bellvue 1951
" " -Poudre Supply 1951
" " -Horticulture 1950
" " -Horticulture 1949
" " -Bellvue 1950
Plastic S.C.S. Meter-Bellvue 1951
U.S.B.R. Meter-Bellvue 1951
" " Poudre Supply 1951
Seepage Rate Ratio Seepage Meter / Inner Ring
Seepage Meter Rate-Feet per Day
Poudre S. 1951 S.C.S.
Poudre S. 1951 U.S.B.R.
Bellvue 1951 Pl. S.C.S.
Bellvue 1951 S.C.S
Bellvue 1951 U.S.B.R.
Hort. 1950 S.C.S.
Bellvue 1950 S.C.S.
Hort. 1949 S.C.S.
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Figure 37

that no one single line could represent the data as there seems to be a separate calibration curve for each type of meter in each location. For the condition where a high seepage rate exists, the ratio of the results by the two methods comes nearer to one. The ratios for the different types of meters seem to fall in the same area in the figure for a given location of the meters. The rates for the conventional and plastic type SCS meters are very nearly the same. This would indicate that the presence or absence of sunlight does not materially affect the operation.

The well permeameter tests made during the season in the vicinity of the seepage rings, are not directly comparable with the seepage ring rates since the solution of the formula for the well permeameter gives a value of the permeability K rather than the seepage. However, the effect of depth tests on the seepage rings yield values of K which can be compared with the results of the well permeameter tests and disturbed sample permeability tests. For Bellvue, the well permeameter gave values for the permeability ranging from 0.25 to 0.50 foot per day. These values compare to a range of from 0.085 to 0.100 foot per day as determined from the effect of depth tests and 4 to 5 feet per day for the disturbed sample tests. One well permeameter test made at Bellvue in the outer ring after the water was shut off and the surface allowed to dry, gave a permeability of 1.80 feet per day.

For the well permeameter tests made near the Poudre Supply seepage rings a range of values of from 0.09 to 0.50 foot per day was determined for the permeability. In this case, as previously explained, there was considerable difference in the soil in the area around the seepage rings. The disturbed sample permeability tests gave values of K ranging from

0.03-0.05 foot per day to 0.20-0.90 foot per day. These values compare to a range of from 0.005 to 0.020 for K as determined for the outer ring.

A series of well-permeameter tests along a section of the North Poudre Supply Canal gave values of the seepage to be expected, ranging from 0.24 to 0.36 foot per day. This seepage rate will be checked by ponding after excavation of the canal is complete.

The results of ponding tests on a section of the completed Poudre Supply Canal are given in table 7. The rate for the initial filling was 0.30 foot per day as compared to 0.075 for the same water depth at a later filling. However, the second filling was from flood water which contained a large amount of silt and consequently would tend to reduce the seepage. Seepage meter tests along the bottom of the canal at the time of the first filling gave rates which were much less than those from ponding. This was probably the result of horizontal permeabilities being much greater than vertical permeabilities.

Inflow-outflow measurements on the Arthur Ditch which showed consistent losses in 1950 were again made along the same section in 1951. This time consistent gains were determined for practically every measurement. This method of determination should not be used unless the seepage losses are tremendous as the normal error of measurement may be greater than most losses.

SUMMARY

A study of the seepage rates as shown by the seepage rings indicates that the effect of the length of time that water has been in a canal is a very important factor in the determination of seepage losses. Although other factors such as silting and chemical reactions which usually reduce the seepage rate were eliminated in this study, the seepage rates nevertheless continued to decrease from season to season.

"Effect of Depth" tests again demonstrated the fact that the seepage rate is not directly proportional to the depth of water in the canal but is proportional to the depth plus some length of soil column. This means that there is still seepage at the time that water reaches zero depth. This phenomenon was utilized in determining the permeability K of the soil within the seepage rings.

It was noted that after several months of operation there seemed to be an hourly fluctuation of the seepage rates from the seepage rings. This fluctuation, which was as much as 50 percent, still existed even after the rates were corrected to a standard temperature. The variation was apparently due in part of the relationship of the water and soil temperatures.

Piezometers installed within the seepage rings as well as in the general vicinity, indicate that the operation of the seepage rings had no effect on the position of the water table. The fluctuation was due to factors which had no connection with the seepage ring operation.

Tests with the seepage meters indicated that if care was exercised in the installation, the rates were approximately in the same range as those shown by the seepage rings. In some types of soil it was necessary to wait several days after installation until the seepage meter gave a rate comparable to the seepage ring rate. An attempt to develop a calibration curve for the seepage meters based on a ratio of the seepage ring and seepage meter determinations was unsuccessful. A separate curve seemed to exist for each type of seepage meter in a particular location.

The results of tests for the determination of the permeability using the well-type permeameter did not compare favorably with the results of the tests using the seepage rings or the disturbed sample permeameters. The difference is probably due to the fact that the well-permeameter is more of a measure of the horizontal permeabilities whereas the seepage rings are a measure of vertical permeability. It is believed that the well permeameter does have merit if used for investigation of seepage losses from proposed canals.

Ponding tests on a reach of a newly excavated canal also showed the importance of time in seepage determinations. The rate at the second filling was only one-fourth that for the first filling. In this instance, however, silting probably had some effect. Seepage meter tests on the same reach of canal gave results that were generally much less than the results of the ponding tests. These large differences were apparently due to the fact that the seepage meter tests were made in the bed of the canal whereas most of the seepage probably occurred from the side slopes.

Inflow-outflow measurements although carefully made, showed consistent gains in a section where large losses were known to exist.

FUTURE PROGRAM

With the conclusion of the 1951 testing season, the seepage from sandy loam, clay loam, and heavy clay has been studied with the seepage rings. Yet to be investigated is seepage from fine sand and medium clay. The present plan is to remove the soil from the rings at the Bellvue Laboratory down to the underlying gravel and to replace it with sand. This will permit a study of the seepage as measured by the seepage rings and seepage meters from a very porous material.

Since the surface soil at the Poudre Supply Plot is practically impermeable and the underlying material is known to be fairly permeable, there is a possibility that the upper one foot or more could be removed and the rings lowered so that a medium clay could be tested. However, the location of the rings may have to be changed in order to find the desired type of soil.

The use of tensiometers in connection with the seepage rings is contemplated to determine if negative forces are involved.

Further work is proposed in studying the effect of temperature on the seepage rates as shown by the seepage meters. Soil thermometers will be installed in the seepage rings for this purpose. The hourly variation in seepage rates by the seepage rings and well permeameter as previously discussed, seems to be partly due to the relationship of the water and soil temperature. This variation, no doubt, also applies to the rate as shown by the seepage meters. Another effect which may be a factor in the seepage meter operation is the "scale effect". This means that the ratio of horizontal and vertical permeabilities must be considered in determining the size of the seepage meter if the rate is to be compared with a standard pond. The importance of the scale effect will also be investigated.

In order to study the effect of the depth to the water table on the seepage rate, the construction of some special equipment is proposed. A watertight tank approximately 12 feet in diameter and 3 feet deep will be built. This tank will be filled with soil and a ring 6 feet in diameter similar to those used in the seepage rings will be set inside the large tank. The small ring will be filled with water and the seepage rate will be measured when the ground water in the large tank is held at various levels. Soils of several different types will be tested.

A further possibility for study is in the actual excavation of a section of a small canal after first making well permeameter tests along the center line. The section need not be more than 3 feet deep, have a 5 foot bottom with 1-1/2:1 side slopes and a length of from 15 to 20 feet. Ponding tests as well as seepage meter determinations would be made after filling the pond with water.

If construction of the North Poudre Supply Canal is completed this season along the section where well permeameter tests were made in 1951, ponding tests will be made to check the accuracy of the well permeameter tests. This will probably entail the building of earth dams at each end of the section. Other sections of the North Poudre Supply Canal, which are not yet excavated, will be investigated for possibility of further tests with the well-type permeameter. Ponding and seepage meter tests would then be possible after excavation has been completed.

A possibility for further study of the well-type permeameter may exist along a section of the Poudre Supply Canal. Although the Canal has been completed it would be possible to make tests at a distance outside the disturbed area on each side of the canal. Intermittent water deliveries during the 1951 season would permit ponding to check the determinations.

Records will be kept in the same manner as before on temperature, barometric pressure, precipitation and evaporation. Study of the physical and chemical characteristics of the soil in the area under investigation will be continued. The quality of the water used in the study will also be tested. Such other tests as may be required for special purposes will be made when necessary.

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