EARTH LININGS FOR SEEPAGE CONTROL:

Evaluation of Effectiveness and Durability

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PREFACE

This publication presents information regarding the effectiveness and, more importantly, the durability of various earth materials used for seepage control in irrigation canals and reservoirs. An important objective of the study was to evaluate any change in effectiveness of the earth-lining materials when blended with various quantities of bentonite.

The studies were of such a nature that the investigations are pertinent today, even though the study was concluded in 1966. It is believed that the information is unique in that the direct seepage measurements through earth-lining materials reported herein span a greater time period than any other previously reported.

The research project was a cooperative venture between the Agricultural Research Service of the U.S. Department of Agriculture, the Bureau of Reclamation of the U.S. Department of Interior, and the Utah Agricultural Experiment Station. A preliminary analysis of the data presented in this report was completed by Teh-hong Hsu and was reported by him as a Master of Science thesis entitled "Evaluation of Earth Linings for Seepage Control" from Utah State University, Logan, Utah, in 1967.

The test lining installations were directed by, and all seepage measurements and final analyses were completed by, the Agricultural Research Service. The research investigation was funded partially through an agreement with the Region 4 office of the Bureau of Reclamation under the Bureau's Lower-Cost Canal Lining Program. Bureau of Reclamation personnel were also involved in the installation of the lining materials. The continuing and direct participation by members of the staff of the Chief Engineer, Denver, Colo., and the Regional Director, Salt Lake City, Utah, was excellent and most beneficial in completing the study. Part of the facilities for completing the work and some funding were provided by the Utah Agricultural Experiment Station.

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Agricultural Research Service
UNITED STATES DEPARTMENT OF AGRICULTURE
In Cooperation with
Bureau of Reclamation
UNITED STATES DEPARTMENT OF INTERIOR
and the
Utah Agricultural Experiment Station

EARTH LININGS FOR SEEPAGE CONTROL:

Evaluation of Effectiveness and Durability

by
A. R. Dedrick and C.W. Lauritzen[1]

INTRODUCTION

Seepage losses in canals and reservoirs can be controlled to a degree by lining with various materials, such as asphalt, butyl rubber, chemical treatment, concrete, earth, and plastics. To evaluate the effectiveness and serviceability of earth linings, several types of selected soils were installed in seepage test channels at Logan, Utah. The evaluation consisted of periodic seepage measurements made throughout the irrigation season over a period of 19 years, from 1948 through 1966.

In this report, the data collected are summarized and analyzed for significance to determine lining effectiveness and durability.

FACILITIES FOR MEASURING SEEPAGE

The need for more accurate information on the performance of canal and reservoir linings resulted in the construction in 1945 of an outdoor seepage laboratory on the Logan River. Water for the seepage laboratory was taken directly from the river and was classified as C2-S1[2,3] when sampled in 1949. The facilities included four seepage channels, each subdivided into eight 20-foot sections (fig. 1). Of the 32 available test sections, 15 were used for the earth-lining studies reported in this paper. The additional test sections were used to study asphalt linings.[4] The channels were constructed of reinforced concrete without a surface gradient. Each section was provided with a perforated galvanized pipe located longitudinally in the center of each section for collecting the seepage. A galvanized conveyor pipe, attached to the collection pipe, discharged into an open collection pit for measurement of the seepage (fig. 2).

Galvanized sheet-metal dividers were used to separate test sections in each channel. Each metal divider was made in three sections of single thickness. The sections were then riveted together, and the unit was made watertight by soldering the joints and rivet heads. The dividers were placed in grooves provided in the bottom and sides of the channel and were sealed. The sides and bottom of each section were painted with RC-1 asphalt to insure a waterproof system. A channel with the dividers in place and ready for the subgrade material is shown in figure 3.

Full-size channel sections were designed to eliminate some of the boundary effect associated with small laboratory permeameters. Problems such as sampling technique, sample size, and mixture uniformity of the lining materials were minimized; whereas items such as intermittent water delivery, natural freezing and thawing conditions, and microbiological activity were more typical of natural field conditions. Essentially, zero water velocity within a channel section was an unnatural canal condition but would be similar to a reservoir application.

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[1] Agricultural engineer and soil scientist (deceased), Agricultural Research Service, U.S. Department of Agriculture, Logan, Utah.

[2] Thorne, J. P., and Thorne, D. W. The irrigation waters of Utah. Utah Agr. Expt. Sta. Bul. 346, 64 pp. 1951.

[3] United States Department of Agriculture. Agr. Handb. 60, Diagnosis and improvement of saline and alkali soils. 160 pp. 1954.

[4] Lauritzen, C. W., and Dedrick, A. R. Asphalt linings for seepage control: evaluation of effectiveness and durability of three types of linings. U.S. Dept. Agr. Tech. Bul. 1440, 61 pp. 1972.

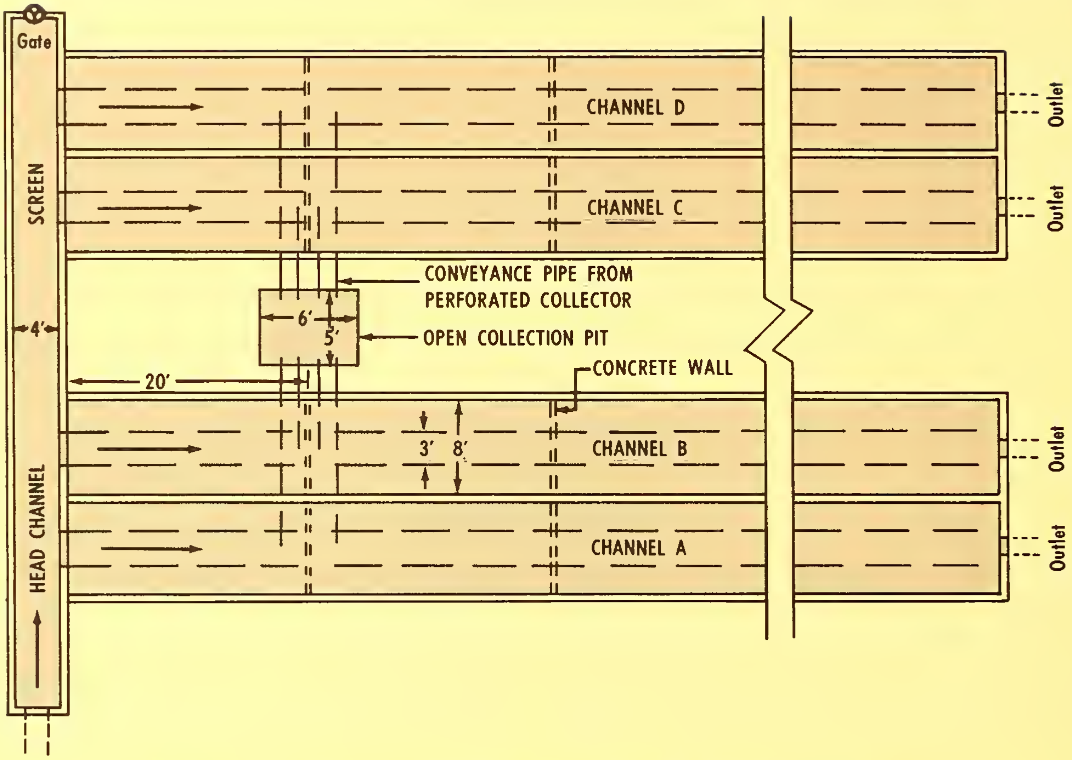

FIGURE 1. – Layout for experimental channels used in seepage control tests.

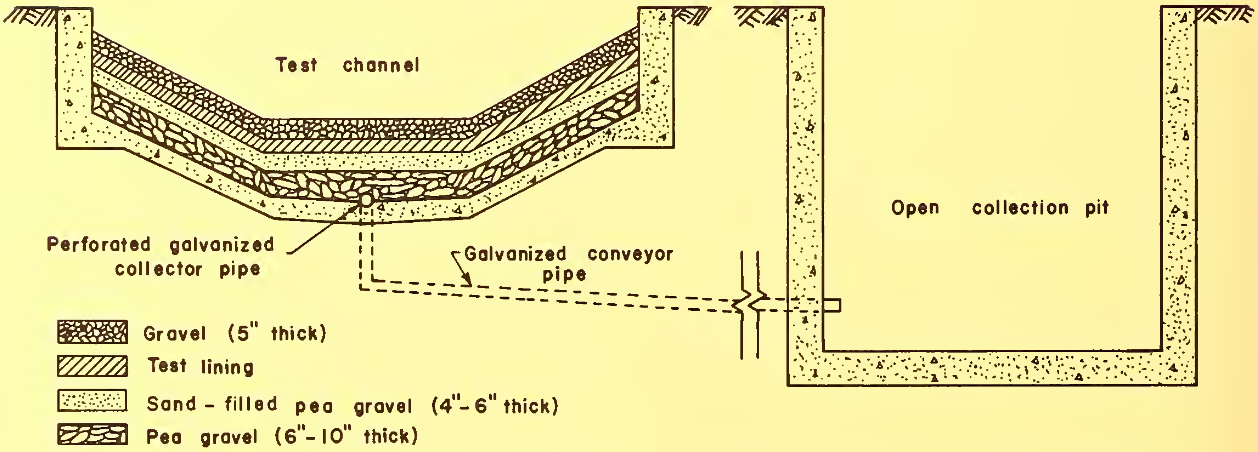

FIGURE 2. – Cross section of experimental seepage-control channels and open pit for collecting seepage.

FIGURE 3. – Experimental seepage-control channel before addition of subgrade material. Metal dividers are already sealed in place in the concrete basin.

LINING INSTALLATION

Material in the channel sections consisted of a 6- to 10-inch layer of pea gravel (¼- to ¾-inch-diameter aggregates) topped with a 4- to 6-inch layer of sandfilled pea gravel (three parts gravel to one part sand by volume). This material was placed around the drainpipe and over the sides and bottom of the channel. A sandfilled layer was used, because graded gravel subgrades caused piping in previous experiments using the test channels. The subgrade elevation in all sections was set so that the completed linings with the required cover would be at approximately the same elevation. In all cases, the subgrade was placed to provide a freeboard of approximately 3 inches on the linings, irrespective of the cover.

The subgrade was shaped by a screed or template (fig. 4) mounted on pneumatic tires. The unit traveled on concrete curbs along the channel. After the subgrades were in place and shaped, the drains to the sections were capped and water was admitted into the channel to settle and compact the subgrades. The level of the water was raised above the height of subgrade and allowed to remain for a 24-hour period, after which the water was drained from the channel. This procedure was repeated several times. Before placing the experimental earth linings, the subgrades were reshaped and allowed to dry.

A quantity of soil material (by weight) necessary to produce a 4-inch compacted lining was used. The quantity of water required to

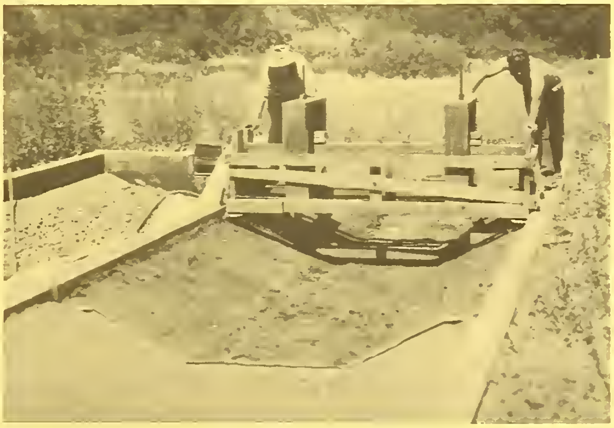

FIGURE 4. – Screed used to shape the subgrade and experimental liner.

attain maximum compaction of the lining materials was determined using the Proctor method[5] (table 1). The soil material was mixed in a 3½-cubic-foot concrete mixer at a moisture content equal to about half the optimum for maximum compaction. Additional water required to bring the mixture to the optimum moisture percentage was added to each batch by sprinkling the material as it was dumped from the mixer into the channel. After mixing thoroughly, the material was covered with a canvas for several hours to allow a more uniform moisture distribution. The material was distributed on the subgrade and shaped with the screed to a uniform thickness. The measured lining thickness averaged 0.38 feet (4 - 5/8 inches), which was about 15 percent thicker than planned (table 1).

A pneumatic backfill tamper was used for compaction. The sideslopes were compacted first by making a pass up the slope in the loose material and returning over the same area. This prevented dislodging of the soil from the sideslopes. A second pass was made longitudinally, beginning at the base of the slope and working up. The linings were reshaped with the screed, following each pass with the tamper. Tamping was repeated three times in each direction, resulting in six passes over the entire lining. When finished, the surface of the linings was firm and relatively smooth. Each lining was core sampled (fig. 5) immediately after installation in 1948 for channel C and 1952 for channel B. The apparent specific weights ranged from 79 to 92 percent of the maximum Proctor value (85 percent average), which indicated that compaction was inadequate (table 1). If the lining materials had been compacted to the required thickness, the final apparent specific weight would have been more nearly equal to maximum Proctor. The fact that the moisture content of the compacted soils was considerably lower than optimum probably contributed to less than optimum compaction.

A general view of an entire channel with earth-lined sections, before it was covered with gravel, is shown in figure 6. After the soil was compacted, a 3- to 5-inch layer of 1- to 2-inch gravel was placed over the lining material to serve as a protective coating. The gravel covering was shaped with the screed. Linings with and without the gravel cover are illustrated in figure 7.

FIGURE 5. – Coring device used to obtain samples for apparent specific weight determinations.

FIGURE 6. – Appearance of linings in channel C before covering with gravel. The lining in the foreground is C-8.

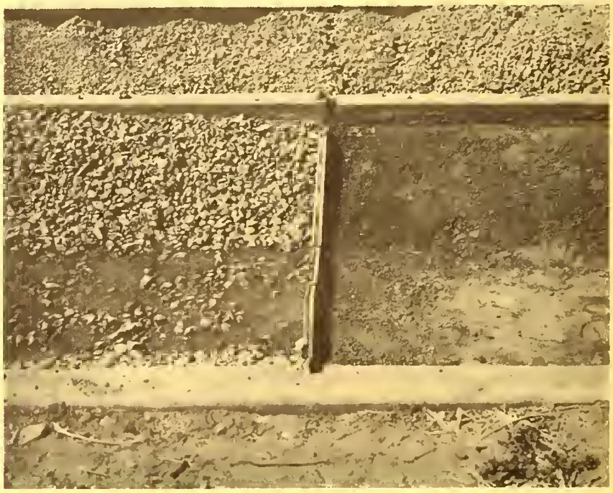

FIGURE 7. – An earth lining before covering with gravel is shown on the right. The lining to the left of the divider has been covered with gravel.

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[5] Proctor, R. R. Fundamental principles of soil compaction. Engin. News-Rec. 111 (9): 245-248. 1933.

TABLE 1. — Information associated with the earth-lining materials studied in the seepage test channels at Logan, Utah, which included installation and removal dates; apparent specific weight, moisture content, and thickness immediately after installation; texture; soluble salts; exchangeable sodium; average water depth in channels; and seepage coefficient

[TSL, Trenton sandy loam; OSL, Oasis silt loam; MSL, Millville silt loam; SLSL, Salt Lake silt loam; SCL, silty clay loam; SL silt loam; CL, clay loam; RB, Redmond bentonite; HB, Henrieville bentonite]

Test channel and section No.	Type of lining material	Installed	Removed	Optimum moisture content to attain maximum compaction	Apparent specific weight		Percent of Proctor	Moisture content	Lining thickness	Textural class		Total soluble salts	Exchangeable sodium	Water depth, *d*	Seepage coefficient (C_s)
					Maximum Proctor	Maximum Core									
		Year	*Year*	*Pw percent*	*Lb/ft*^{3}			*Pw percent*	*Ft*	*Original*	*1966*	*Meq/100 g*		*Ft*	$\left[\frac{Ft^3/ft^2/day}{ml/s}\right]$
B-1 - - -	OSL	1952	1966	20	106	90	85	23.8	0.35	Silt loam	Silty clay	8.20	7.43	0.73	0.0243
B-2 - - -	MSL + 10 parts RB	1952	1966	17	111	90	81	15.5	.40	- - - do - - -	loam	.27	.20	.76	.0237
B-3 - - -	TSL + 10 parts HB	1952	1966	18	110	92	84	13.2	.38	Sandy loam	Sandy clay	.15	.11	.80	.0231
B-4 - - -	TSL + 20 parts HB	1952	1966	18	105	93	88		.37	- - - do - - -	- - - do - - -	.20	.15	.76	.0238
B-5 - - - - - - -	do - - - -	1952	1966	18	105	95	90	12.2	.36	- - - do - - -	- - - do - - -	.25	.20	.73	.0243
B-6 - - -	TSL + 20 parts RB	1952	1966	15	112	98	87	9.5	.31	- - - do - - -	Sandy loam	.30	.26	.85	.0224
B-7 - - - - - - -	do - - - -	1952	1966	15	112	101	90	10.6	.32	- - - do - - -	- - - do - - -	.30	.25	.79	.0233
B-8 - - -	TSL + 10 parts RB	1952	1966	15	112	103	92	7.2	.36	- - - do - - -	- - - do - - -	.21	.18	.80	.0232
C-2 - - -	OSL	1948	1966	20	107	87	81	24.2	.38	Silt loam	Silty clay	1.89	1.60	1.07	.0196
C-3 - - -	TSL + 10 parts HB	1948	1966			87		12.9	.44	Sandy loam	Sandy loam	.16	.14	.99	.0205
C-4 - - -	MSL + 5 parts RB	1948	1966		105	76	72	9.0	.44	Silt loam	Loam	.24	.21	1.00	.0204
C-5 - - -	SLSL + 5 parts RB	1948	1966		99	88	89	13.2	.42	- - - do - - -	Silt loam	.26	.21	.98	.0206
C-6 - - -	USBR lining (SCL) material	1948	1966		115	95	83	6.4	.39	Silty clay loam	Clay loam	.23	.20	1.01	.0202
C-7 - - -	USBR lining (SL) material	1948	1966		113	94	83	6.9	.44	Silt loam	Silt loam	.18	.16	.95	.0210
C-8 - - -	USBR lining (CL) material	1948	1966		119	101	85	6.1	.38	Clay loam	Loam	.19	.16	1.03	.0200
	Mean						85		.38						

LINING MATERIALS

The earth-lining materials studied were of the following four general soil types: (1) clay loam, (2) silty clay loam, (3) silt loam, and (4) sandy loam (see table 1). During the years of study, settlement of fine soil materials suspended in the water caused some textural changes as reflected by the textural classifications of the original material and from samples classified in 1966 (table 1). Three soil series (Oasis, Millville, and Trenton) were included along with three lining materials transported from Utah County. The Utah County soils were from the same source as material used for lining a section of the Provo River reservoir canal in the 1940's under the direction of the U.S. Bureau of Reclamation (USBR). The specific combinations were:

Soil series or source	*Soil type*
Utah County	Clay loam
Utah County	Silty clay loam
Millville, Salt Lake, Oasis, and Utah County	Silt loam
Trenton	Sandy loam

In previous studies, Lauritzen and Israelsen[6] showed that the permeability of sandy loam was greatly reduced by the addition of bentonite, with some reduction shown for a like addition to silt loam. The coefficient of permeability for Trenton sandy loam cores compacted at optimum moisture was 19.9 ft/yr. When 2 parts bentonite to 100 parts Trenton sandy loam (2 percent by weight) were added, the permeability decreased to 1.58 ft/yr; with 5 parts, the permeability was 0.072 ft/yr; and with 10 parts, the permeability was 0.017 ft/yr. For Millville silt loam the permeability without additions was 0.757 ft/yr, whereas a permeability of 0.173 ft/yr was measured when 5 parts bentonite were added. These preliminary measurements illustrated the advantages of bentonite additions to soils to be used as earth-lining materials. Hence, different quantities of bentonite were added to the Trenton sandy loam and Millville silt loam soils reported in this paper. The finely ground bentonite used was from two Utah sources — Redmond bentonite from a high-grade deposit near Redmond, and Henrieville bentonite from a deposit near Henrieville. The amount of bentonite added to the two soils was either 5, 10, or 20 parts to 100 parts soil (percent by weight). Trenton sandy loam and Millville silt loam without bentonite were not tested in the channels since water losses were expected to be excessive and could destroy the lining by piping of the lining material into the subgrade material. Oasis silt loam was evaluated without the addition of bentonite since preliminary core permeability was lower than Trenton sandy loam with 10 parts bentonite added.[7]

The chemical properties of the earth linings were determined from core samples taken at completion of the study in 1966. The total soluble salts and exchangeable sodium are shown in table 1.

Hereafter, the following abbreviations will be used in the text:

TSL = Trenton sandy loam
OSL = Oasis silt loam
MSL = Millville silt loam
SLSL = Salt Lake silt loam
SCL = Silty clay loam
SL = Silt loam
CL = Clay loam
RB = Redmond bentonite
HB = Henrieville bentonite

For example, the abbreviation TSL + 10 HB refers to a soil-bentonite mixture of 100 parts Trenton sandy loam and 10 parts Henrieville bentonite. The materials installed and tested in the channels, along with the date of installation and removal, are shown in table 1.

LABORATORY HYDRAULIC CONDUCTIVITY MEASUREMENTS

The earth-lined test channels were sampled after the seepage tests were completed in 1966. These samples were used to determine the laboratory hydraulic conductivity of the earth-lining materials using constant-head permeameters. Distilled water was used for the studies.

Soil cores,[8] 3-1/8 inches in diameter, were taken in triplicate from the earth-lined test channels. The cores, hereafter referred to as undisturbed samples, were carefully handled to minimize cracking. Heat-shrinkable plastic tubing was used to encase the core samples. This process eliminated water leakage between the core and the tubing and insured all water movement was through the soil column. The length of the soil column ranged from 3½ to 4¾ inches, depending on the thickness of the test liners. The head of water used ranged from 30 to 50 inches. As large a head as possible was used without causing channeling through the sample.

Standard procedures[9] were used to prepare

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[6] Lauritzen, C.W., and Israelsen, O. W. Earth linings for irrigation canals and reservoirs. Soil Sci. Soc. Amer. Proc. 13: 531-538. 1948.

[7] See footnote 6.

[8] Hayden, Clarence W., and Heinemann, William H., Jr. A hand-operated undisturbed core sampler. Soil Sci. 106(2): 153-156. 1968.

[9] See footnote 3.

five permeability samples from disturbed soil taken from each test channel, hereafter referred to as dry-pack samples. The glass permeameters were 1-3/8 inches in diameter. The length of the soil column ranged from 3¼ to 7½ inches, depending on the volume that 100 or 200 g of oven-dry soil occupied. The head of water ranged from 27 to 30 inches.

DATA COLLECTION

Seepage records were started in 1953 for channel B and 1948 for channel C and were continued until 1966 for both channels. Measurements were started as early as May and ended in mid-December in some years; however, measurements were taken from June through September (somewhat in excess of 100 days) in most years. In the early years, measurements were made at intervals averaging 7 days, and in the mid-years, at intervals averaging 4 days; during the last years, daily readings were taken.

The measurement frequency during some of the years was inadequate for analysis. In such cases, a value for a particular year was approximated from calculations relating seepage rate to years of exposure. Some of the early records were quite erratic. This inconsistency may be attributed, in part, to unrecorded periods of water removal from channels, to water-depth variation in the channels, and to recording errors. During the latter years of the study, unusual changes during the measuring period were recorded.

Water that seeped through the lining materials was collected periodically. The volume of water collected during a measured time period was converted to a seepage rate by the use of a seepage coefficient.

A seepage coefficient, C_s, was developed that converted the discharge rate in millimeters per second for an entire test section to a rate per unit area of wetted perimeter in cubic feet per square feet per day (see "Appendix"). The resultant coefficient was dependent upon depth of water in a section. The depth of water varied from section to section but was constant for any one section; hence, C_s was constant for each section (table 1).

The volume of percolate from the laboratory permeability samples was measured several times a day for a 17-day period. The hydraulic conductivity was calculated from the general equation:

$$k = \frac{QL}{tAH}$$

where Q is the volume of water passing through the soil column in time (t); A is the area of the soil column, and k is the average hydraulic conductivity in the soil column of length (L) over which there is an hydraulic head difference (H).[10]

DATA ANALYSIS PROCEDURE

To study the effect of length of time that each lining was in operation for each of the years, the resulting seepage rate was plotted with respect to time after water was introduced into the channel section (fig. 8). From examination of these plottings, any erratic data were eliminated from the analysis if the variations were unexplainable, and the effect of time on seepage was visually and graphically studied. Also, from these plottings average seepage rates for each of four 25-day periods throughout the test year (approximately 100 days) were determined graphically, even though only a few readings may have been available for a given year. The average seepage rate values, for all years of the study, are shown in table 2.

The average seepage rate for each lining material for each 25-day period was related to time after installation. Regression analyses were conducted where seepage (the dependent variable) was transformed with the logarithm. The curves and coefficients for the best fit lines are shown in the Appendix (figs. 13 through 27). The resultant relationship allowed two important operations. First, missing yearly data could be estimated and, second, the effectiveness of the lining material over a period of years could be determined within each use period. If the regression coefficient were positive, the seepage significantly increased and effectiveness diminished; if the regression coefficient were

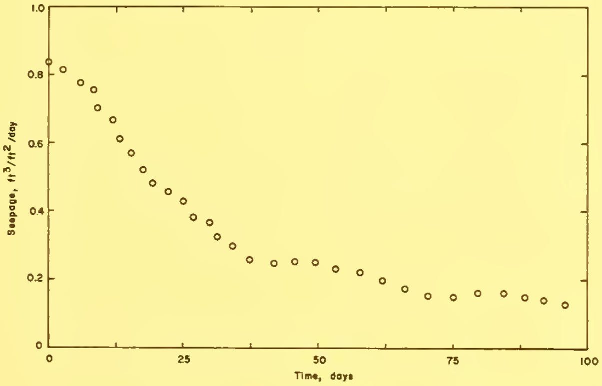

FIGURE 8. — Representative seepage-rate curve.

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[10] See footnote 3.

TABLE 2. — *Seepage losses measured from 15 experimental earth-lined channels evaluated at Logan, Utah*

TSL, Trenton sandy loam; OSL, Oasis silt loam; MSL, Millville silt loam; SLSL, Salt Lake silt loam; SCL, silty clay loam; SL, silt loam; CL, clay loam; RB, Redmond bentonite; HB, Henrieville bentonite

Test channel and section No.	Type of lining material	Observation period from beginning of seepage year	Seepage rates for the following years[1]																		
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
		Number of days	*Ft³/ft²/day*																		
B-1	OSL	0– 25	0.002	0.000	0.003	0.148	0.009	0.002	0.000	0.130	0.700	0.222	0.565	2.000	2.190	10.500	0.000	0.000	0.000	0.000	0.000
		26– 50	.003		.002	.140	.055	.002		.055	.150	.244	.415	1.300	.820	6.000					
		51–75	.009			.132	.015	.002		.125	.175	.190	.325	1.400	1.050						
		76–100	.020			.125	.004	.001		.110	.200	.295	.295		2.000						
B-2	MSL + 10 parts RB	0– 25	.003	0.137	.845	1.320	.840		0.510	.798	1.380	1.050	1.050	3.910	2.980	4.910					
		26– 50	.002	.060	.430	.700	.520		.402	.520	1.080	.500	.800	2.350	1.020	3.610					
		51– 75	.004	.055	.320	.490	.320		.320	.335	.620	.310	.420	1.020	.600						
		76–100	.006	.000	.350	.410	.212		.282	.199	.480	.300	.210		.600						
B-3	TSL + 10 parts HB	0– 25	.010	.106	.160	.720	1.120	.400	.445	.860	2.380	.910	1.000	2.150	1.220	1.380					
		26– 50	.008	.080	.128	.442	.720	.245	.355	.519	1.400	.600	.800	1.820	.850	1.750					
		51– 75				.280	.550	.185	.263	.315	.820	.420	.550	.780	.530						
		76–100				.170	.450	.167	.205	.218	.530	.300	.300		.380						
B-4	TSL + 20 parts HB	0– 25	.198	.035	.144	.410	.121	.025		.763	.920	.650	.920	2.220	2.450	1.470					
		26– 50	.115	.031	.101	.225	.111	.010		.295	.350	.230	.700	1.950	1.850	1.810					
		51– 75	.075	.036		.135	.101	.010		.162	.210	.205	.400	1.150	1.250						
		76–100	.058	.046		.087	.091			.118	.180	.160	.200		1.600						
B-5	TSL + 20 parts HB	0– 25		.035	.032	.193	.056	.007	.033	.155	1.010	.526	.731	1.870	1.170	1.420					
		26– 50		.037	.030	.104	.027	.009	.031	.060	.440	.322	.473	1.550	.870	1.400					
		51– 75		.030	.030	.060	.015	.010	.030	.045	.280	.226	.300	1.080	.710						
		76–100		.035	.035	.054	.011		.029	.045	.200	.175	.210		.460						
B-6	TSL + 20 Parts RB	0– 25	.000	.000		.003	.004	.007	.018	.231	1.630	.478	.415	1.530	.780	1.360					
		26– 50	.000	.000		.001	.003	.005	.015	.097	.700	.248	.245	1.400	.600	1.330					
		51– 75	.000	.001		.000	.003	.004	.013	.044	.300	.144	.158	1.010	.490						
		76–100	.000	.001		.001	.002	.003	.011	.032	.180	.100	.115		.250						
B-7	TSL + 20 Parts RB	0– 25	.000		.000	.001	.012	.007	.012	.100	.723	.270	.298	.800	.386	.800					
		26– 50			.000	.001	.011	.006	.012	.058	.270	.165	.198	1.000	.405	.880					
		51– 75				.001	.011	.005	.011	.044	.128	.118	.147	.730	.351						
		76–100				.001	.009	.004	.098	.038	.085	.099	.118		.211						
B-8	TSL + 10 parts RB	0– 25		.019	.082	.255		.155	.392	.320	1.540	1.050	.580	1.020	.950	.668					
		26– 50		.022	.056	.168		.125	.206	.302	1.150	1.220	.432	1.110	.810	.846					
		51– 75		.050		.170		.093	.132	.208	.900	.880	.295	.850	.700						
		76–100		.090		.235		.063	.098	.250	.650	.680	.203		.580						
C-2	OSL	0– 25	.004	.001	.000	.000		.000	.000	.001	.003	.020	.011	.031	.590	1.890	0.600	1.580	3.440	2.850	5.690
		26– 50	.002	.000	.000	.000		.000	.000	.001	.002	.018	.009	.025	.390	.800	.280	.780	2.820	1.780	5.040
		51– 75	.002	.000	.000	.000		.000		.001	.001	.010	.006	.019	.160	.420	.200	.490	1.510	1.150	
		76–100	.001	.000	.000	.000		.000		.001	.000	.006	.004	.014	.080	.250	.200	.350		.850	
C-3	TSL – 10 parts HB	0– 25	.009	.007	.022	.000	.099	.561	1.380	1.180	1.800	1.460	.725	.620	3.910	8.600	1.610	2.030	5.320	3.650	4.060
		26– 50	.011	.009	.022	.000	.110	.387	1.180	.800	.650	.750	.481	.512	2.110	3.550	1.000	1.140	4.150	1.610	4.200
		51– 75	.013	.011	.023	.000	.106	.350	1.000		.410	.610	.365	.405	1.060	1.950	.730	.710	2.290	.990	
		76–100	.053	.013	.021	.000	.101	.365	.810		.380	.600	.300	.300	.630	1.250	.600	.480		.940	
C-4	MSL + 5 parts RB	0– 25	.011	.040	.210	.586	.344	1.090	1.010	.940	1.290	1.010	.780	.520	1.980	4.690	1.740	1.850	2.850	2.340	2.030
		26– 50	.010	.061	.321	.390	.404	.690	1.100	.480	.560	.560	.490	.460	1.540	2.570	.960	1.160	4.030	1.510	3.440
		51– 75	.009	.092	.225	.194	.361	.680	1.220		.300	.490	.410	.400	.750	1.460	.670	.650	2.050	1.040	
		76–100	.008	.085	.154		.218	.700	1.300		.200	.420	.260	.310	.410	.910	.530	.490		.820	

C-5	SLSL + 5 parts RB	0– 25	.290	.635	.740	1.040	.760	2.100	1.950	1.220	2.250	.850	.720	.800	3.180	6.300	1.750	2.180	4.650	3.090	5.320
		26– 50	.235	.540	.860	.910	.780	1.260	2.140	.580	.950	.410	.390	.520	1.810	2.620	.860	1.130	5.560	1.220	4.940
		51– 75	.182	.445	.550	.800	.600	1.190	1.950		.340	.300	.250	.690	.620	1.320	.550	.580	2.360	.840	
		76–100	.130	.349	.280		.340	1.740	2.230		.110	.280	.100	.900	.260	.720	.420	.330		.760	
C-6	USBR lining material (SCL)	0– 25	.119	.069	.054	.074	.125	.430	.480	.348	1.000	.567	.480	2.710	.699	1.350	1.070	.910	2.290	2.200	1.690
		26– 50	.195	.075	.049	.115	.098	.214	.572	.158	.640	.505	.362	2.700	.596	.850	.620	.700	2.750	1.540	2.370
		51– 75	.100	.096	.044	.141	.084	.205	.626		.490	.390	.212	2.480	.340	.610	.500	.510	1.520	1.080	
		76–100	.084	.088	.039	.141	.077	.287	.481		.410	.360		2.200	.195	.380	.410	.360		.680	
C-7	USBR lining material (SL	0– 25	.150	.281	.140	.170	.300	.780	.890	1.050	1.110	.960	.480	.590	.890	2.350	1.100	1.040	2.450	2.090	2.530
		26– 50	.150	.201	.139	.235	.253	.780	1.210	.890	.980	.770	.490	.300	.800	2.240	.780	.800	3.280	1.490	2.120
		51– 75	.150	.200	.120		.234	.780	1.350	.930	.890	.660		.210	.660	1.850	.500	.550	2.250	1.320	
		76–100	.150	.238	.105		.210	.780	.950	1.060	.810	.770		.200	.530	.800	.350	.330		1.280	
C-8	USBR lining material (CL)	0– 25	.094	.235	.089	.243	.202	.477	.598	.600	.865	.475	.480	.598	.828	1.650	.745	.655	1.200	1.400	1.810
		26– 50	.088	.152	.078	.234	.152	.455	.633	.382	.556	.345	.330	.373	.668	1.070	.450	.455	1.850,	1.080	1.700
		51– 75	.088	.126	.067	.208	.130	.420	.656		.375	.302	.320	.273	.509	.700	.341	.312	1.680	1.060	
		76–100		.101	.056	.191	.110	.370	.650		.260			.235	.350	.410	.306	.228		.740	

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[1] Year 1 refers to 1953 for sections in channel B and 1948 for sections in channel C.

negative, the effectiveness of the lining improved with time.

Since the coefficient of determination was in excess of 50 percent for nearly all analyses, corrected seepage rates for each 25-day period for each year were taken from the regression equation. This technique was used to smooth the data and help take out any unusual observations that appeared to be in error. Years that showed erratic data, with respect to the overall test, were disregarded in calculating the regression equation.

Linear correlation was used to relate laboratory hydraulic conductivity to channel seepage. Laboratory hydraulic conductivity, from both undisturbed cores and dry pack, was compared with channel seepage for each individual year from 1953 through 1966. The resultant coefficients of determination from the linear correlation analyses were then used as an indicator of how well channel seepage and hydraulic conductivity measurements were correlated. Hydraulic conductivity measured from the two sample types — undisturbed and dry pack — were also compared.

RESULTS AND DISCUSSION

Seepage Losses

The average rate of seepage through the earth linings over a 14-year period following installation ranged from 0.02 ft^3/ft^2/day to 0.78 ft^3/ft^2/day, a difference of about 40 times (table 3). Seepage rates for 11 of the 15 earth-lining materials studied were 0.43 ft^3/ft^2/day or less (maximum relative seepage was 1.8). Only one lining material (one section of OSL) controlled the average seepage for as much as 13 years to less than 0.1 ft^3/ft^2/day. The yearly seepage rates during the early years of the study were, in many instances, less than 0.1 ft^3/ft^2/day (table 3) with some as low as 0.001 ft^3/ft^2/day (App. figs. 13 through 27 and table 2).

Seepage rates reported from core studies conducted in 1946 through 1948 by Lauritzen and Israelsen[11] showed TSL to be as much as 3,000 times more permeable than OSL. MSL was nearly 100 times more permeable. By adding either RB or HB to TSL, at the 20-part rate, the measured seepage from the test channels, averaged over a 14-year period, was about 1½ times more than that measured through the OSL liners (0.33 ft^3/ft^2/day for TSL compared to 0.22 ft^3/ft^2/day for OSL). The seepage control increased when the amount of bentonite added to the TSL was increased, at least up to the portions reported in this paper.

The higher seepage rate with 10 parts bentonite added to MSL as compared to 5 parts is contrary to what would be expected and what Lauritzen and Israelsen found when using soil cores. The high average seepage rate was a result of excessive increases in the seepage rate after only a few years in operation (App. fig. 14). Initially, the seepage rate from the MSL with 10 parts bentonite was lower than when 5 parts were used (compare *c* values in App. figs. 14 and 23). An addition of as little as 5 parts bentonite to MSL improved the seepage control of the earth material to a level nearly comparable to OSL.

Contrary to the benefits derived from the addition of bentonite to TSL and MSL found in this study and by Lauritzen and Israelsen, the effectiveness of SLSL as a lining material may have decreased with the addition of bentonite. Such is suggested since Lauritzen and Israelsen found that the permeability was zero from SLSL cores with 5 parts RB; whereas, from this study, the average seepage rate was 0.78 ft^3/ft^2/day.

The average seepage rates for two of the materials transported from Utah County were identical (0.32 ft^3/ft^2/day for the CL and SCL) whereas seepage through the Silt Loam was 0.48 ft^3/ft^2/day. This indicates that the average seepage rate was related to the soil textural class in that the higher the clay content of the soil the lower the seepage.

Seepage Change During a Season and Effect of Intermittent Water Delivery

Seepage rates decreased, in many instances significantly, throughout the season when continually wet for all linings studied (figs. 8, 9, and 10). In all cases, the trends throughout the year were downward. Coefficients were developed for an equation which described the average daily seepage rate throughout the season (table 4). The equation was of the form $S = a(10)^{b'T'}$, where S is the seepage rate in ft^3/ft^2/day, T' is time from initial water input to a channel, a' is the initial seepage rate at time (T') equals zero, and b' (regression coefficient) is the slope of the curve when the seepage rate is expressed as the logarithm and time is expressed linearly. The average value of b' was -0.0054 with a standard deviation of 0.0017 (table 4). This means that approximately 68 percent of the regression coefficients were between -0.0037 and -0.0071 (-0.0054 ± 0.0017).

The initial seepage rate varied considerably for the various liners as shown by a' in table 4.

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[11] See footnote 6.

TABLE 3.— Relative seepage control maintained by 15 experimental earth-lined channels tested at Logan, Utah

[TSL, Trenton sandy loam; OSL, Oasis silt loam; MSL, Millville silt loam; SLSL, Salt Lake silt loam; SCL, silty clay loam; SL, silt loam; CL, clay loam; RB, Redmond bentonite; HB, Henrieville bentonite]

Type of lining material	Seepage rate	Relative seepage[1]	Time that average seepage rate ≤ 0.1 Ft^3/ft^2/day
	Ft^3/ft^2/day		*Years*
TSL + 20 parts RB	0.24	1.0	9
Do	.41	1.7	9
TSL + 10 parts RB	.40	1.7	3
TSL + 20 parts HB	.26	1.1	7
Do	.40	1.7	4
TSL + 10 parts HB	.58	2.4	0
Do	.31	1.3	6
OSL	.02	.1	13
Do	.43	1.8	7
MSL + 10 parts RB	.77	3.2	2
MSL + 5 parts RB	.43	1.8	1
SLSL + 5 parts RB	.78	3.2	0
USBR lining material (CL)	.32	1.3	0
USBR lining material (SCL)	.32	1.3	2
USBR lining material (SL)	.48	2.0	0

[1] All materials are rated in comparison to TSL with 20 parts RB. Data represent average values for 14-year period, where year 1 refers to 1953 for sections in channel B and 1948 for sections in channel C.

Low initial seepage rates generally corresponded to low average yearly seepage rates discussed in the previous section and in table 3.

Seepage rates were high immediately after drying periods (fig. 11). The seepage then decreased with time by an amount that is characteristic of that lining material. If water delivery were intermittent, then the resulting average seepage for a season would be excessive if the initial seepage rate for the material were high. Conversely, low initial seepage rate materials would result in low average seasonal rates irrespective of how the water was delivered — continuous or intermittent.

Change in Seepage Rate Over a Period of Years

The average seepage rate decreased in some instances significantly throughout the season. The shape of the seasonal seepage-time curves were the same for all years of the study; however, as the years progressed, the average yearly seepage rates changed. The changing seepage over a period of years is a measure of lining durability.

The relationship between seepage and years in operation was studied and the rate of change estimated (App. figs. 13 through 27). The seepage rate, representing each successive 25-day period for each lining material, was plotted against years of service. A semilog regression of seepage on years fit the measured data quite closely. To determine whether or not the seepage increased or decreased significantly over the years, a t-test was used to evaluate the hypothesis that the regression coefficient was equal to zero. If the slope of the regression line, as shown by the t-test, were significantly different from zero, the seepage significantly changed over the years.

The coefficient of determination associated with the regression analysis was usually greater than 0.50, which indicated a reasonably good fit of the points. All regression coefficients of the 60 lining material-time periods studied were positive, with 53 significantly different from zero at the 5-percent level of significance, which reflects that in nearly all cases the earth linings deteriorated significantly over the years.

Of further interest is the degree of seepage increase. The equation described by the data is of the form $S = c(10)^{bT}$, where S is seepage rate, T is years, c is seepage rate at time (T) equals zero, and b is the slope of the seepage (log)-time curve (regression coefficient). The degree of change is best illustrated by the value of b reflected by the steepness of the curves in Appendix figures 13 through 27.

The mean value of b for 15 lining materials was 0.1396, with a standard deviation of 0.0863. Hence, approximately 68 percent of the b values were between 0.0533 and 0.2259. Large b values indicate rapid deterioration toward the end of the study, as illustrated by the OSL in channel section C-2 (App. fig. 21). If the regression coefficient were about average or less, the deterioration proceeded at a relatively constant rate and did not reach a point where the deterioration increased sharply as the years of service increased. Such a deterioration relationship is illustrated by the SLSL + 5 parts RB in channel section C-5 (App. fig. 24).

Seepage through some linings, although initially high, did not change a great deal through the years, whereas others started low and increased rather rapidly after a number of years. These variations are illustrated by the relative position of a lining material with respect to other linings studied for successive years (table 5). The relative effectiveness of the linings was indicated by numerals from 1 to 15 with the

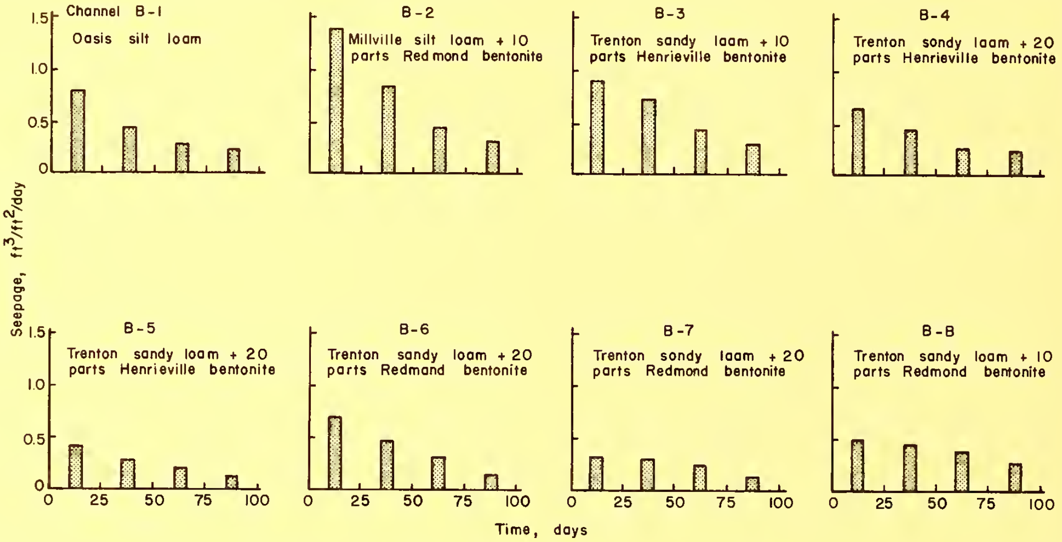

FIGURE 9. – Changes in seepage rates of experimental liners tested in channel B. Data represent average rates for first 100 days for all years of study.

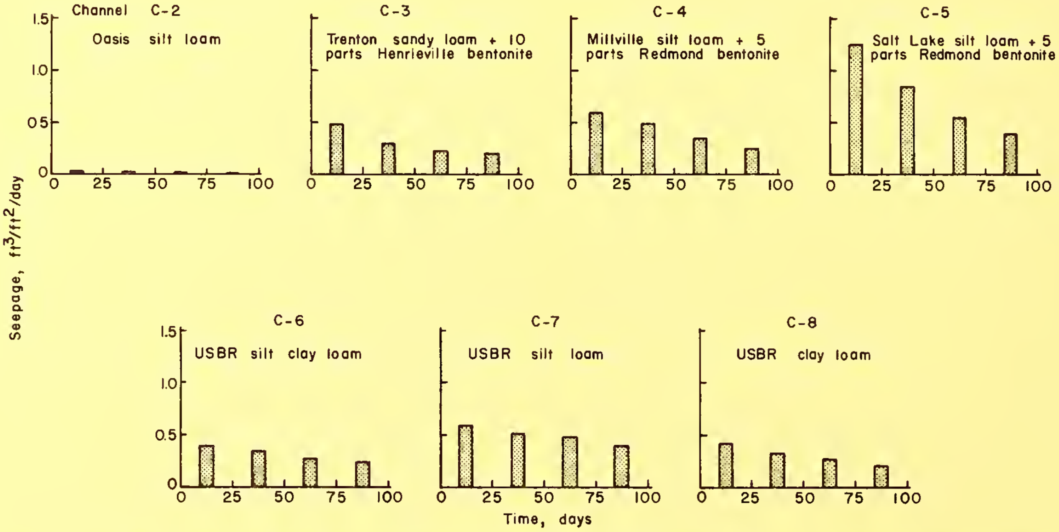

FIGURE 10. – Changes in seepage rates of experimental liners tested in channel C. Data represent average rates for first 100 days for all years of study.

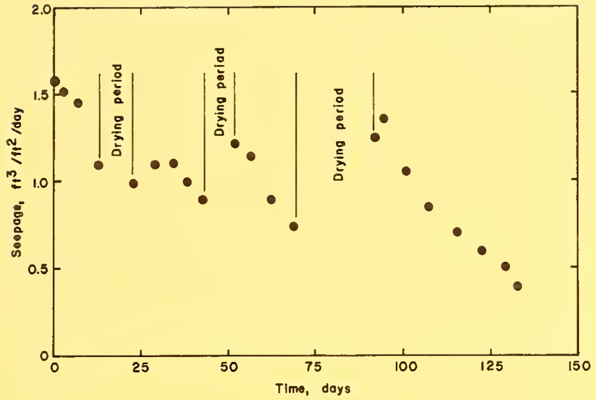

FIGURE 11. — Effect of intermittent water delivery on seepage rates of experimental liner. Chart is seepage-time curve from section C-3, 1954.

lowest value corresponding to the lowest seepage rate. If the relative rating of a material were higher for later years, the lining improved with respect to the other linings or the rate of deterioration of the other linings was higher than the material being considered.

The earth linings for which the seepage rates increased the most (*b* value greater than 0.2259) were both replications of OSL and TSL + 20 RB. The earth linings for which the seepage rates increased the least (*b* value less than 0.0533) were SLSL + 5 RB, USBR-SL, and USBR-CL.

These facts appear to be contrary to the previous discussion involving average seepage rate (table 3), in that those materials increasing the most during the study period also, in many instances, were those that yielded the lowest average seepage rate for the period. In contrast, the materials changing the least during the study period also yielded the highest average seepage rate for the period. These discrepancies can be explained by examining table 5 and Appendix figures 13 through 27. The low average seepage rate materials (OSL and TSL + 20 RB) resulted from very low initial seepage rates during the first years of the study followed by rapid increases (relative number in 1953 in table 5 was low as compared to relative number in 1966). Initially, high average seepage rate materials (SLSL + 5 RB, USBR-SL, USBR-CL) were more porous than the other linings studied, but the seepage increase with time was small. The USBR-CL is a prime example, having started in the twelfth position and ended in 1966 in the second position.

To insure a low seepage rate over a long period of time for a lining material, a low initial seepage rate, *c*, is required followed by a very small or no seepage increase with time — small *b* value (refer to App. figs. 13 through 27). Of the lining materials studied, these characteristics were most nearly found for TSL + 20 HB in channel section B-5 (App. fig. 17), TSL + 10 RB in channel section B-8 (App. fig. 20), and OSL in channel section C-2 (App. fig. 21). This is further confirmed by the relative effectiveness illustrated in table 5 in which the relative position of the above noted earth-lining materials remained essentially constant for the study period.

Over the years, the seepage rate tended to increase more rapidly for the 0- to 25-day period

TABLE 4.— Constants for use in equation describing change in seepage with time throughout the year[1]

[TSL, Trenton sandy loam; OSL, Oasis silt loam; MSL, Millville silt loam; SLSL, Salt Lake silt loam; SCL, silty clay loam; SL, silt loam; CL, clay loam; RB, Redmond bentonite; HB, Henrieville bentonite]

Test channel and section No.	Type of lining material	Initial seepage rate for year (*a*′)	Slope of semilog curve (*b*′)
		Ft³/ft²/day	
B-1	OSL	0.90	−0.0076
B-2	MSL + 10 parts RB	1.85	− .0087
B-3	TSL + 10 parts HB	1.15	− .0066
B-4	TSL + 20 parts HB	.73	− .0063
B-5	do	.50	− .0064
B-6	TSL + 20 parts RB	.86	− .0060
B-7	do	.38	− .0040
B-8	TSL + 10 parts RB	.58	− .0030
C-2	OSL	.04	− .0071
C-3	TSL + 10 parts HB	.53	− .0053
C-4	MSL + 5 parts RB	.73	− .0049
C-5	SLSL + 5 parts RB	1.60	− .0070
C-6	USBR lining material (SCL)	.47	− .0033
C-7	USBR lining material (SL)	.65	− .0020
C-8	USBR lining material (CL)	.47	− .0036

[1] Prediction equation is of the form $S = a'(10)^{b'T'}$
where: S = seepage, ft^3/ft^2/day
T = time, days
a' = initial seepage rate ($T' = 0$)
b' = slope of semilog plot

(early season) than for the 76- to 100-day period (late season) (App. figs. 13 through 27, *b* for 0- to 25-day period greater than *b* for 76 to 100). This would indicate more difference between initial and late-season seepage rates during the last years of the study than during the early years, which is illustrated by the increase in seepage difference with time between the upper and lower curves in Appendix figures 13 through 27.

Laboratory Hydraulic Conductivity

Hydraulic conductivity measured from dry-pack samples averaged from 10 to 35 times more than that measured through undisturbed soil cores.

Hydraulic conductivity from dry-pack samples for the initial day was more closely correlated to initial channel seepage during the early years of the study than during the later years and was about 16 times greater than the channel seepage. This same correlation did not exist when hydraulic conductivity from undisturbed samples was considered. After the hydraulic conductivity became essentially constant (after 13 days), the hydraulic conductivity for both undisturbed and dry-pack samples was closely correlated to channel seepage measured during the final years of the

TABLE 5 — Relative effectiveness of 15 experimental earth-lining materials tested at Logan, Utah[1]

[TSL, Trenton sandy loam; OSL, Oasis silt loam; MSL, Millville silt loam; SLSL, Salt Lake silt loam; SCL, silty clay loam; SL, silt loam; CL, clay loam; RB, Redmond bentonite; HB, Henrieville bentonite]

Test channel and section No.	Type of earth-lining material	Years[2]													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
B-1 - - -	OSL	4	4	4	4	4	4	4	4	4	5	8	12	14	13
B-2 - - -	MSL + 10 parts RB	9	9	9	10	10	12	12	13	14	14	15	15	15	14
B-3 - - -	TSL + 10 parts HB	13	13	13	13	13	13	13	12	12	13	13	13	12	12
B-4 - - -	TSL + 20 parts HB	7	7	7	7	7	7	7	7	9	9	9	11	10	10
B-5 - - -	- - - do - - -	5	5	5	5	5	5	5	5	5	4	4	4	4	5
B-6 - - -	TSL + 20 parts RB	2	2	2	2	2	2	2	3	3	3	3	7	13	15
B-7 - - -	- - - do - - -	3	3	3	3	3	3	3	2	2	2	2	2	5	11
B-8 - - -	TSL + 10 parts RB	8	8	8	8	8	8	8	9	10	10	10	10	9	8
C-2 - - -	OSL	1	1	1	1	1	1	1	1	1	1	1	1	1	1
C-3 - - -	TSL + 10 parts HB	6	6	6	6	6	6	6	6	6	6	6	6	7	7
C-4 - - -	MSL + 5 parts RB	11	11	11	11	12	11	11	11	11	11	11	9	8	6
C-5 - - -	SLSL + 5 parts RB	15	15	15	15	15	15	15	15	15	15	14	14	11	9
C-6 - - -	USBR lining material (SCL)	10	10	10	9	9	9	9	8	7	8	7	5	3	3
C-7 - - -	USBR lining material (SL)	14	14	14	14	14	14	14	14	13	12	12	8	6	4
C-8 - - -	USBR lining material (CL)	12	12	12	12	11	10	10	10	8	7	5	3	2	2

[1] For each year, the lowest value (1) indicates lowest seepage rate, and the highest value (15) indicates highest seepage rate.

[2] Year 1 refers to 1953 for sections in channel B and 1948 for sections in channel C.

study. The hydraulic conductivity from dry-pack samples was about two times more than channel seepage during this period but only about one-tenth as large as channel seepage when undisturbed samples were used.

The high correlation of the dry-pack to channel seepage during the early years was probably due to the sample soil initially being quite similar to soil in a freshly prepared channel. As time progressed, the dry-pack soil settled as water moved through the column and became more like a lining that had been in service for several years. Since the samples were taken from the channels after the seepage study was terminated, hydraulic conductivity from undisturbed samples would be expected to be closely correlated to channel seepage near the end of the study. This was the case, and the more removed in time from the final year of study, the poorer the correlation.

These quantitative comparisons were, however, only applicable to the study situation being reported. Even though laboratory permeability and channel seepage were highly correlated during certain periods of study, various factors, such as water quality, subgrade conditions, temperature and pressure, and entrapped air,[12] could influence the comparative values.

SUMMARY AND CONCLUSIONS

The average seepage rate measured through the 15 earth-lining materials ranged from 0.02 ft^3/ft^2/day for one section of OSL to 0.78 ft^3/ft^2/day for SLSL + 5 parts bentonite over a 14-year period following installation. If the 0.02 ft^3/ft^2/day seepage rate were not included in the range, then all other lining materials were only different by a factor of about three (0.24 to 0.78 ft^3/ft^2/day).

Seepage control through two of the lining materials (TSL and MSL) was improved when bentonite, from either of two sources, was added. Seepage rate decreases were in direct response to increased bentonite content, up to 20 parts with 100 parts soil (maximum used in the study), when added to TSL. The addition of bentonite beyond 5 parts with 100 parts MSL did not appear to yield improved seepage control. Effectiveness of a third lining material (SLSL) may have decreased with the addition of bentonite.

Seepage control was generally best during the early years of the study and gradually decreased as the experimental linings aged. In many instances, the yearly seepage rate was less than 0.1 ft^3/ft^2/day for several years after the linings were installed but increased with exposure time. The seepage rate (S) change with time (T) in years was not linear but increased exponentially according to the equation $S = c(10)^{bT}$. The larger the coefficient b, the greater the seepage increase during the latter years; whereas, if b were relatively small, the increase with years was more gradual.

The seepage rate for the earth-lining materials decreased throughout a season when continually wet. The seepage rate (S) generally decreased the most during the early part of the season and approached a constant rate with time (T). This seasonal change can be described by an exponential equation similar to that discussed in the previous paragraph. In the case of seasonal change, however, the coefficient b would be less than zero (negative). Following periods of drying, seepage rates tended to increase sharply, then decrease, following the form of the original die-off curve. If water were delivered intermittently, and initial seepage rates for the year were excessive, then yearly seepage would be high.

Hydraulic conductivity of dry-pack and undisturbed soil samples taken from the study channels was correlated to seepage losses during certain periods of the study. Initial hydraulic conductivity from dry-packed samples was correlated closely with channel seepage during the early years of the study and was about 16 times greater than channel seepage. After 13 days, near-constant hydraulic conductivity, from both dry-pack and undisturbed soil samples, was closely correlated to the near-constant channel seepage (seepage from 76- through 100-day period) during the final years of study. The hydraulic conductivity from dry-pack samples was about two times more than channel seepage during this period but about one-tenth as large as channel seepage when undisturbed samples were used. Extrapolation of these values to other earth-lining materials should be undertaken with caution.

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[12] Christiansen, J. E. Effect of entrapped air upon the permeability of soils. Soil Sci. 58(5): 355-365. 1944.

APPENDIX

Seepage Coefficient Development — Conversion of Flow Through Test Section Measured in ml/s to Seepage Measured in $ft^3/ft^2/day$

1. A cross-sectional drawing of the test channel section used in the development of the seepage coefficient is shown in figure 12.

2. The seepage coefficient was developed as follows:

Q = total seepage through test section, ml/s

S = seepage loss through unit lining area, $ft^3/ft^2/day$

A = test section wetted perimeter area, ft^2

L = section length, 20 ft

θ = (sideslope 2:1) 26°34′

b = channel bottom width, 3 ft

C_s = seepage coefficient $\dfrac{ft^3/ft^2/day}{ml/day}$

P = wetted perimeter, ft

$$P = 3 + 2d/\sin\theta$$
$$P = 3 + 2d/\sin 26°34'$$
$$P = 3 + 2d/0.446$$
$$P = 3 + 4.48\ d\ \text{(ft)}$$
$$A = L \times P = 20\ (3 + 4.48\ d)$$
$$A = 60 + 89.6\ d$$

Conversion of Q (ml/s) to S ($ft^3/ft^2/day$):

$$S = \frac{Q}{A} = \frac{Q\ \text{ml}}{\text{s}} \times \frac{3{,}600\ \text{s}}{\text{hr}} \times \frac{24\ \text{hr}}{\text{day}} \times \frac{\text{litres}}{1{,}000\ \text{ml}} \times \frac{\text{gal}}{3{,}7854} \times \frac{\text{ft}^3}{7.48\ \text{gal}} \times \frac{1}{(60 + 89.6d)\ \text{ft}^2}$$

$$S = \frac{3.05\ Q}{60 + 89.6d}$$

$$S = C_s\ Q$$

Hence C_s, the seepage coefficient is:

$$C_s = \frac{3.05}{60 + 89.6d}$$

3. From the preceding equation, it can be seen that C_s is a function of depth (d) and is a constant for each test section.

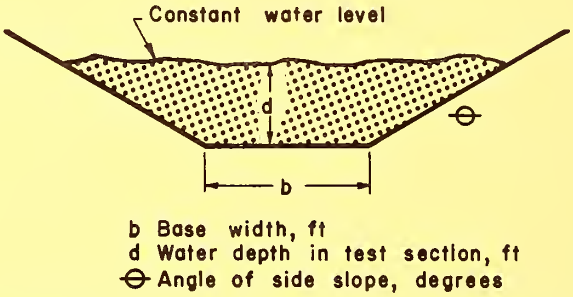
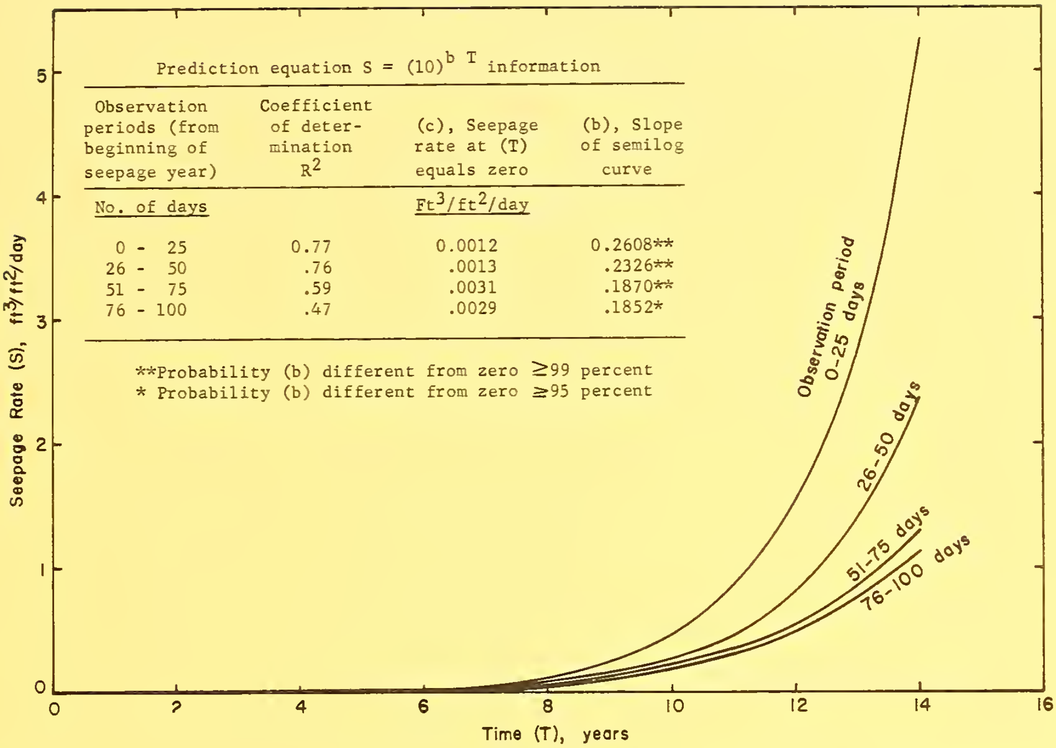


FIGURE 12. — Channel cross section used in development of seepage coefficient.

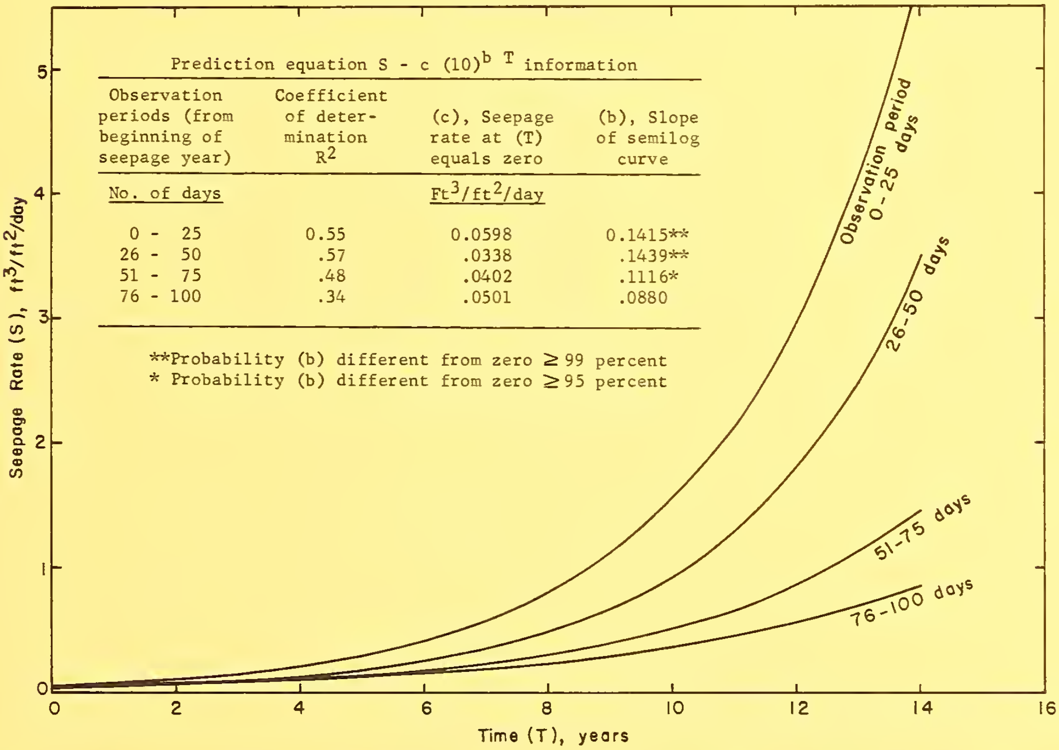


Prediction equation $S = (10)^{b\ T}$ information

Observation periods (from beginning of seepage year)	Coefficient of determination R^2	(c), Seepage rate at (T) equals zero	(b), Slope of semilog curve
No. of days		Ft^3/ft^2/day	
0 - 25	0.77	0.0012	0.2608**
26 - 50	.76	.0013	.2326**
51 - 75	.59	.0031	.1870**
76 - 100	.47	.0029	.1852*

**Probability (b) different from zero ≥99 percent
* Probability (b) different from zero ≥95 percent

FIGURE 13. — Relationship between average seepage rate and years of study for Oasis silt loam in channel B-1.

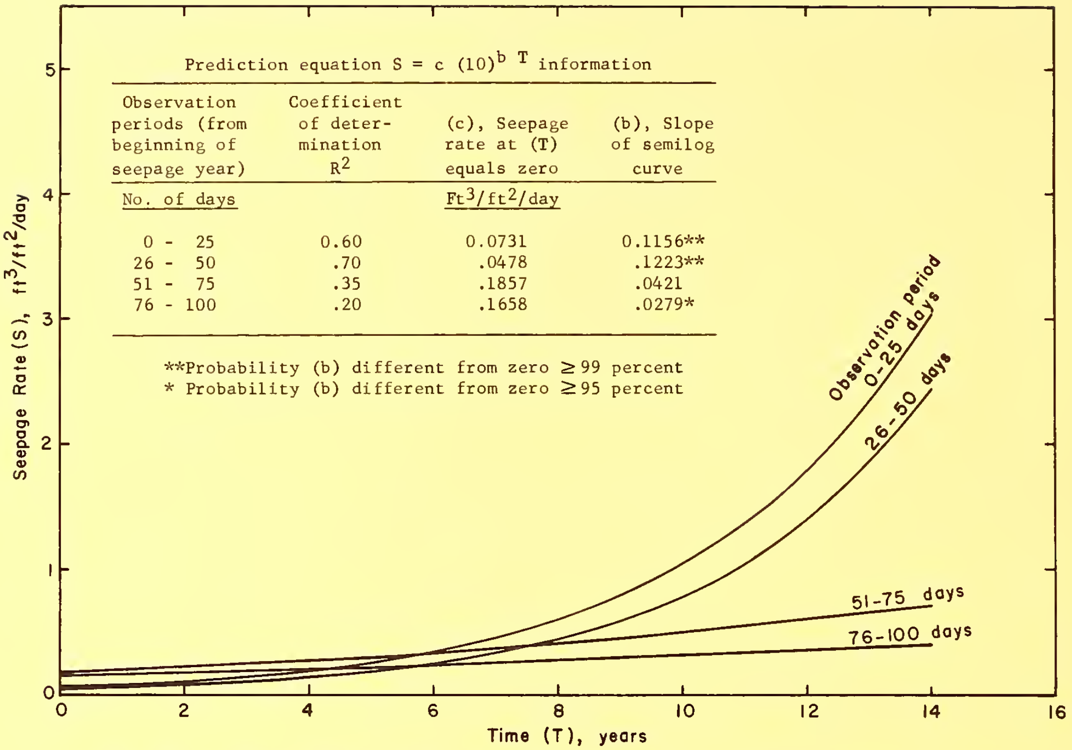


Prediction equation $S - c\ (10)^{b\ T}$ information

Observation periods (from beginning of seepage year)	Coefficient of determination R^2	(c), Seepage rate at (T) equals zero	(b), Slope of semilog curve
No. of days		Ft^3/ft^2/day	
0 - 25	0.55	0.0598	0.1415**
26 - 50	.57	.0338	.1439**
51 - 75	.48	.0402	.1116*
76 - 100	.34	.0501	.0880

**Probability (b) different from zero ≥ 99 percent
* Probability (b) different from zero ≥ 95 percent

FIGURE 14. — Relationship between average seepage rate and years of study for Milville silt loam with 10 parts Redmond bentonite in channel B-2.

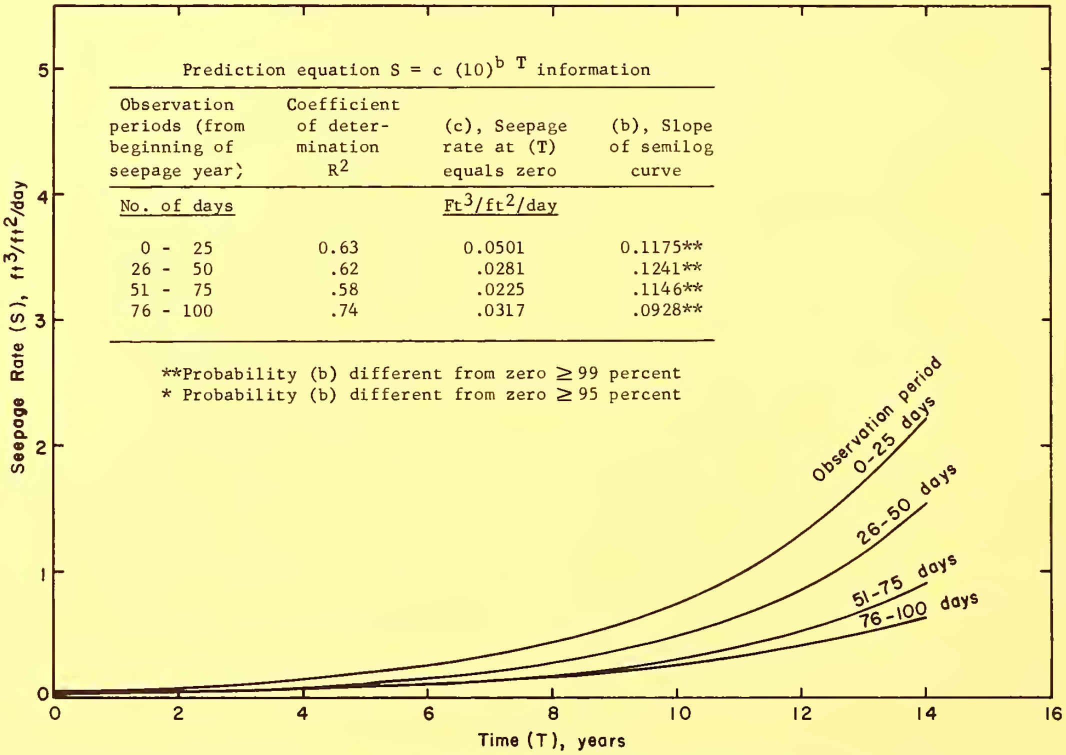


Prediction equation $S = c\ (10)^{b\ T}$ information

Observation periods (from beginning of seepage year)	Coefficient of determination R^2	(c), Seepage rate at (T) equals zero	(b), Slope of semilog curve
No. of days		$Ft^3/ft^2/day$	
0 - 25	0.60	0.0731	0.1156**
26 - 50	.70	.0478	.1223**
51 - 75	.35	.1857	.0421
76 - 100	.20	.1658	.0279*

**Probability (b) different from zero ≥ 99 percent
* Probability (b) different from zero ≥ 95 percent

FIGURE 15. — Relationship between average seepage rate and years of study for Trenton sandy loam with 20 parts Henrieville bentonite in channel B-3.

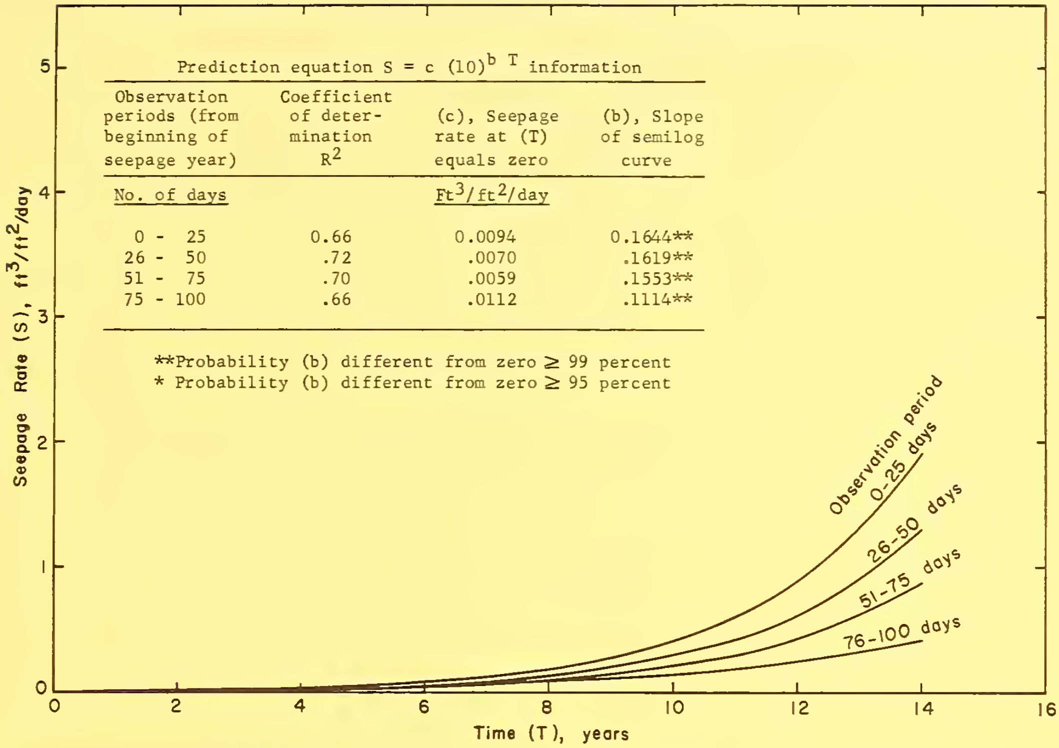


Prediction equation $S = c\ (10)^{b\ T}$ information

Observation periods (from beginning of seepage year)	Coefficient of determination R^2	(c), Seepage rate at (T) equals zero	(b), Slope of semilog curve
No. of days		$Ft^3/ft^2/day$	
0 - 25	0.63	0.0501	0.1175**
26 - 50	.62	.0281	.1241**
51 - 75	.58	.0225	.1146**
76 - 100	.74	.0317	.0928**

**Probability (b) different from zero ≥ 99 percent
* Probability (b) different from zero ≥ 95 percent

FIGURE 16. — Relationship between average seepage rate and years of study for Trenton sandy loam with 20 parts Henrieville bentonite in Channel B-4.

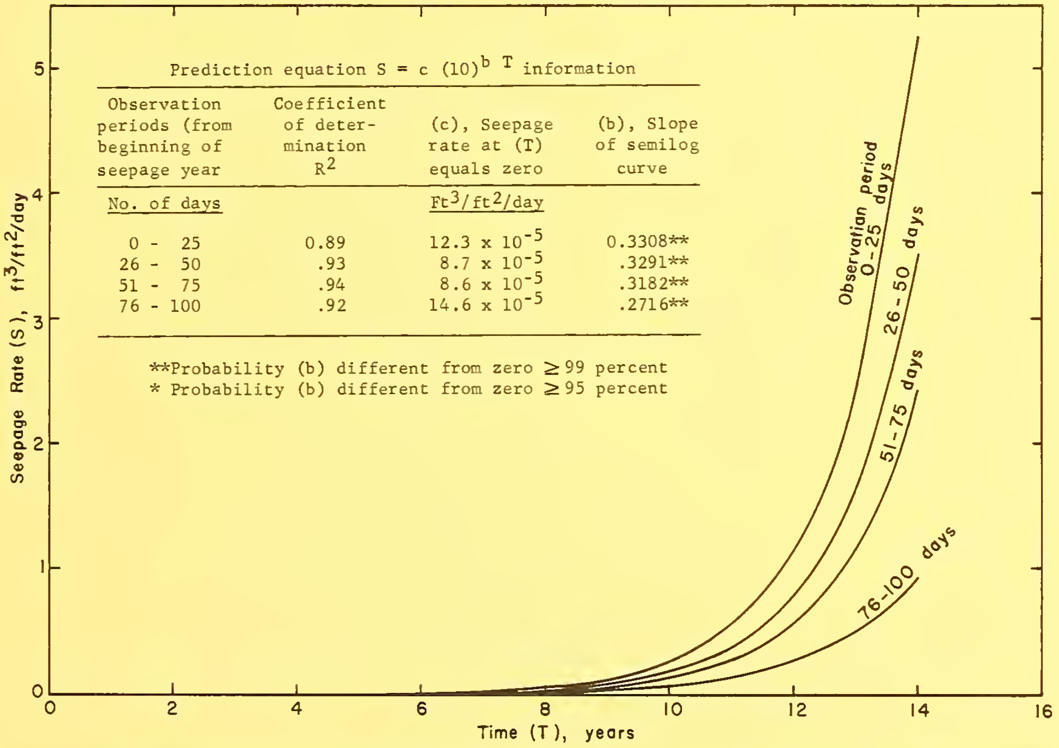


Prediction equation $S = c\,(10)^{b\,T}$ information

Observation periods (from beginning of seepage year)	Coefficient of determination R^2	(c), Seepage rate at (T) equals zero	(b), Slope of semilog curve
No. of days		Ft^3/ft^2/day	
0 - 25	0.66	0.0094	0.1644**
26 - 50	.72	.0070	.1619**
51 - 75	.70	.0059	.1553**
75 - 100	.66	.0112	.1114**

**Probability (b) different from zero ≥ 99 percent
* Probability (b) different from zero ≥ 95 percent

FIGURE 17. — Relationship between average seepage rate and years of study for Trenton sandy loam with 20 parts Henrieville bentonite in channel B-5.

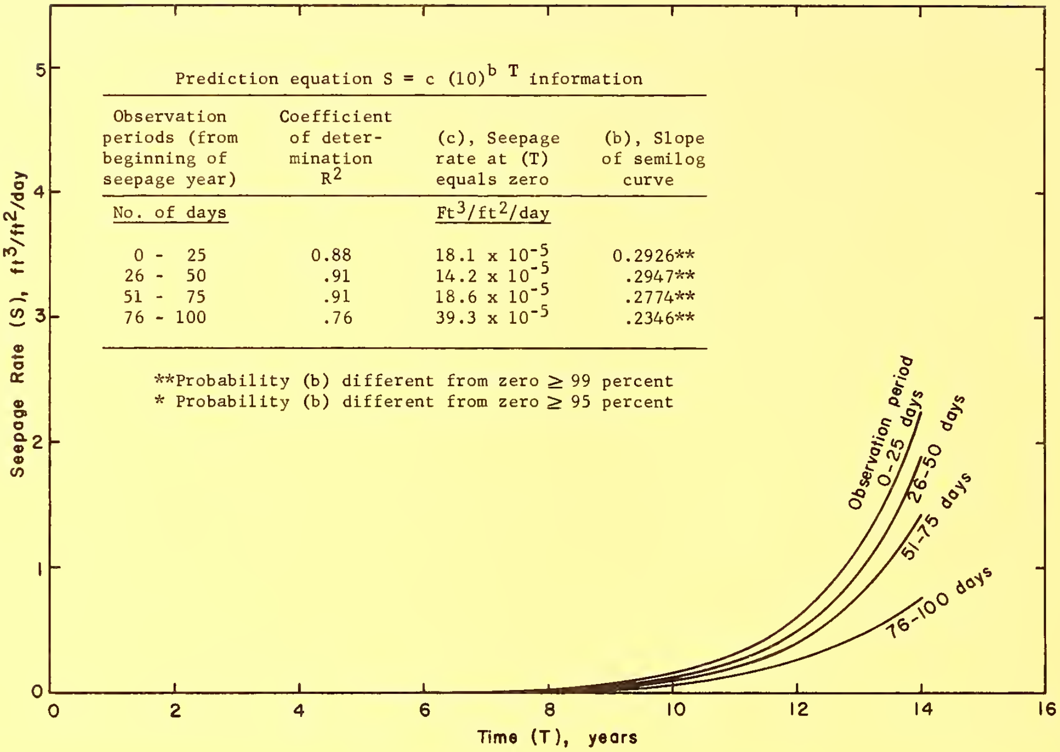


Prediction equation $S = c\,(10)^{b\,T}$ information

Observation periods (from beginning of seepage year	Coefficient of determination R^2	(c), Seepage rate at (T) equals zero	(b), Slope of semilog curve
No. of days		Ft^3/ft^2/day	
0 - 25	0.89	12.3×10^{-5}	0.3308**
26 - 50	.93	8.7×10^{-5}	.3291**
51 - 75	.94	8.6×10^{-5}	.3182**
76 - 100	.92	14.6×10^{-5}	.2716**

**Probability (b) different from zero ≥ 99 percent
* Probability (b) different from zero ≥ 95 percent

FIGURE 18. — Relationship between average seepage rate and years of study for Trenton sandy loam with 20 parts Redmond bentonite in channel B-6.

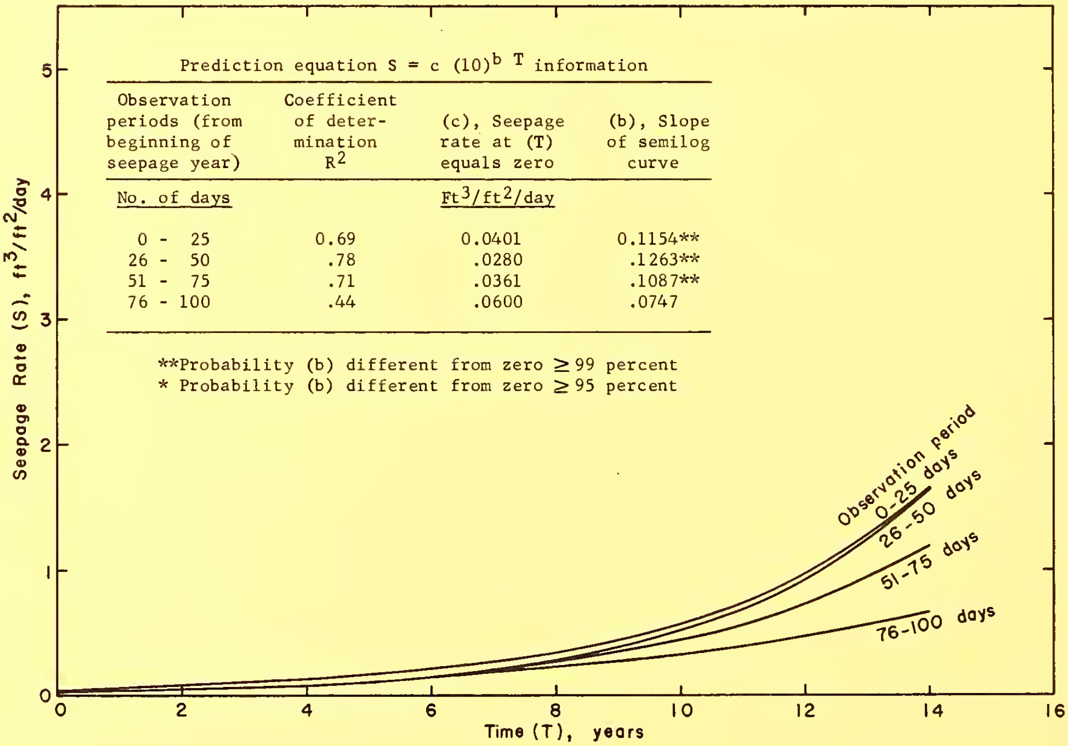


Prediction equation $S = c\ (10)^{b\ T}$ information

Observation periods (from beginning of seepage year)	Coefficient of determination R^2	(c), Seepage rate at (T) equals zero	(b), Slope of semilog curve
No. of days		$Ft^3/ft^2/day$	
0 - 25	0.88	18.1×10^{-5}	0.2926**
26 - 50	.91	14.2×10^{-5}	.2947**
51 - 75	.91	18.6×10^{-5}	.2774**
76 - 100	.76	39.3×10^{-5}	.2346**

**Probability (b) different from zero ≥ 99 percent
* Probability (b) different from zero ≥ 95 percent

FIGURE 19. — Relationship between average seepage rate and years of study for Trenton sandy loam with 20 parts Redmond bentonite in channel B-7.

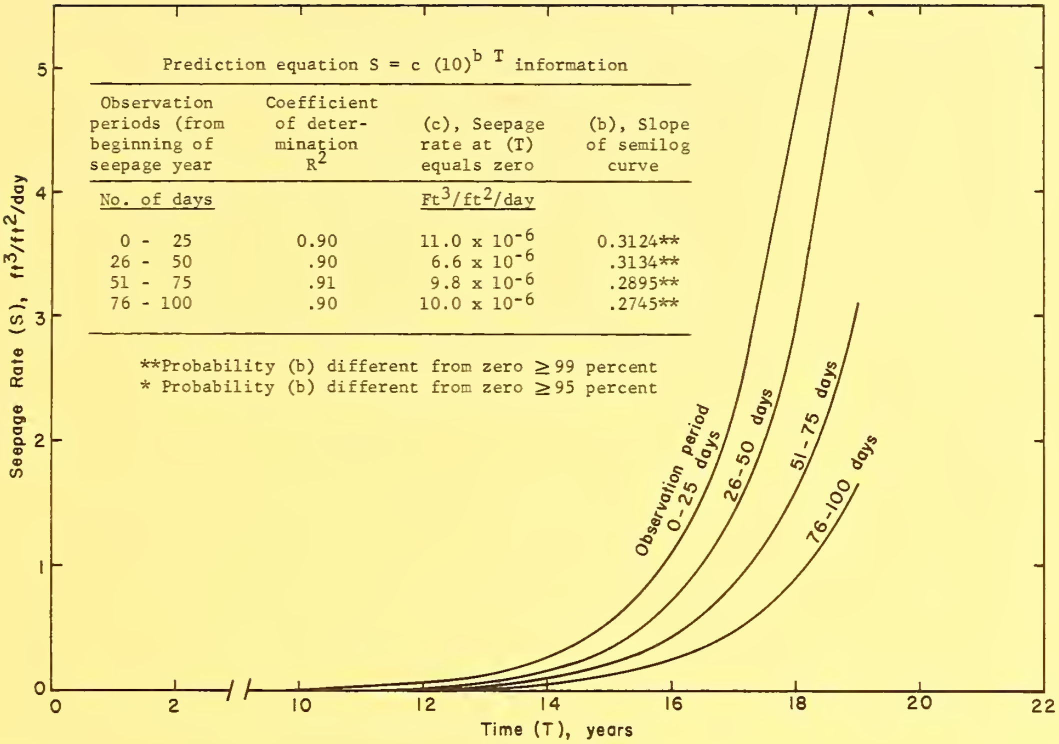


Prediction equation $S = c\ (10)^{b\ T}$ information

Observation periods (from beginning of seepage year)	Coefficient of determination R^2	(c), Seepage rate at (T) equals zero	(b), Slope of semilog curve
No. of days		$Ft^3/ft^2/day$	
0 - 25	0.69	0.0401	0.1154**
26 - 50	.78	.0280	.1263**
51 - 75	.71	.0361	.1087**
76 - 100	.44	.0600	.0747

**Probability (b) different from zero ≥ 99 percent
* Probability (b) different from zero ≥ 95 percent

FIGURE 20. — Relationship between average seepage rate and years of study for Trenton sandy loam with 10 parts Redmond bentonite in channel B-8.

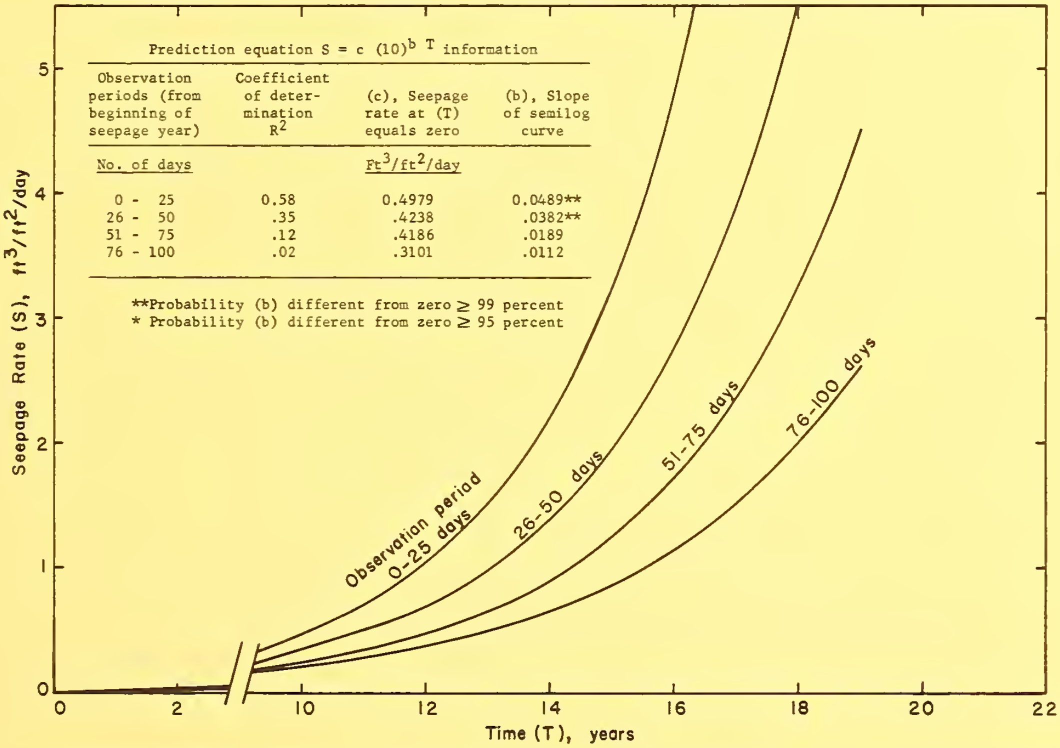


Prediction equation $S = c\ (10)^{b\ T}$ information

Observation periods (from beginning of seepage year	Coefficient of determination R^2	(c), Seepage rate at (T) equals zero	(b), Slope of semilog curve
No. of days		Ft³/ft²/day	
0 - 25	0.90	11.0×10^{-6}	0.3124**
26 - 50	.90	6.6×10^{-6}	.3134**
51 - 75	.91	9.8×10^{-6}	.2895**
76 - 100	.90	10.0×10^{-6}	.2745**

**Probability (b) different from zero ≥99 percent
* Probability (b) different from zero ≥95 percent

FIGURE 21. — Relationship between average seepage rate and years of study for Oasis silt loam in channel C-2.

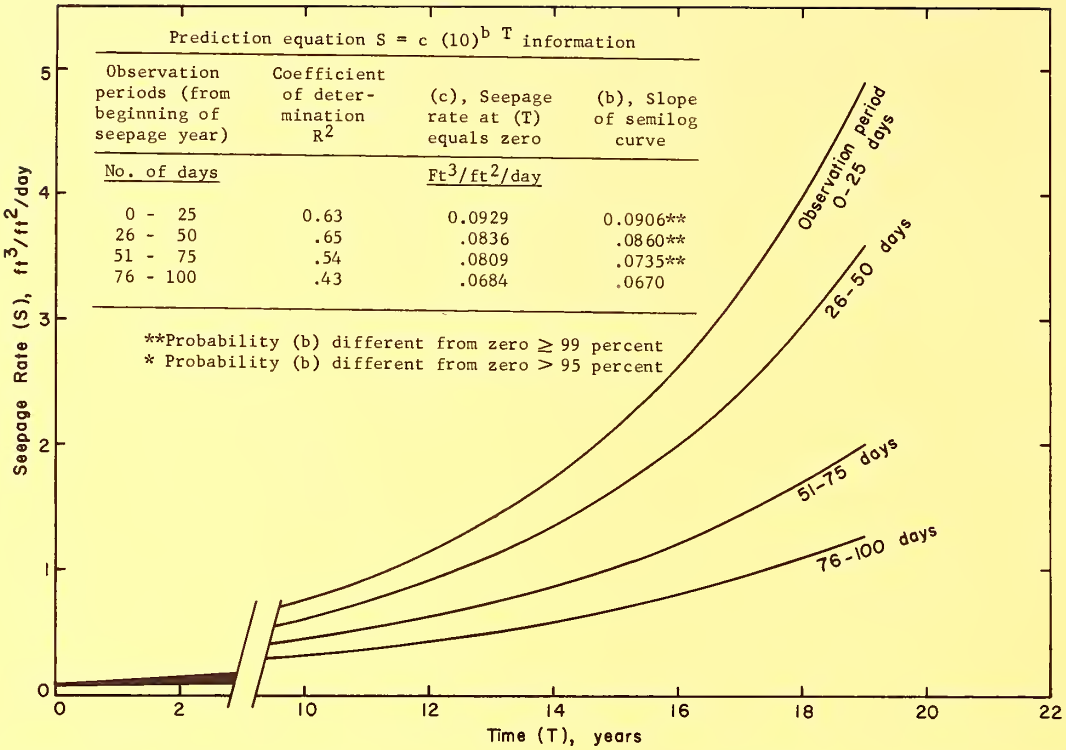


Prediction equation $S = c\ (10)^{b\ T}$ information

Observation periods (from beginning of seepage year)	Coefficient of determination R^2	(c), Seepage rate at (T) equals zero	(b), Slope of semilog curve
No. of days		Ft³/ft²/day	
0 - 25	0.58	0.4979	0.0489**
26 - 50	.35	.4238	.0382**
51 - 75	.12	.4186	.0189
76 - 100	.02	.3101	.0112

**Probability (b) different from zero ≥ 99 percent
* Probability (b) different from zero ≥ 95 percent

FIGURE 22. — Relationship between average seepage rate and years of study for Trenton sandy loam with 10 parts Henrieville bentonite in channel C-3.

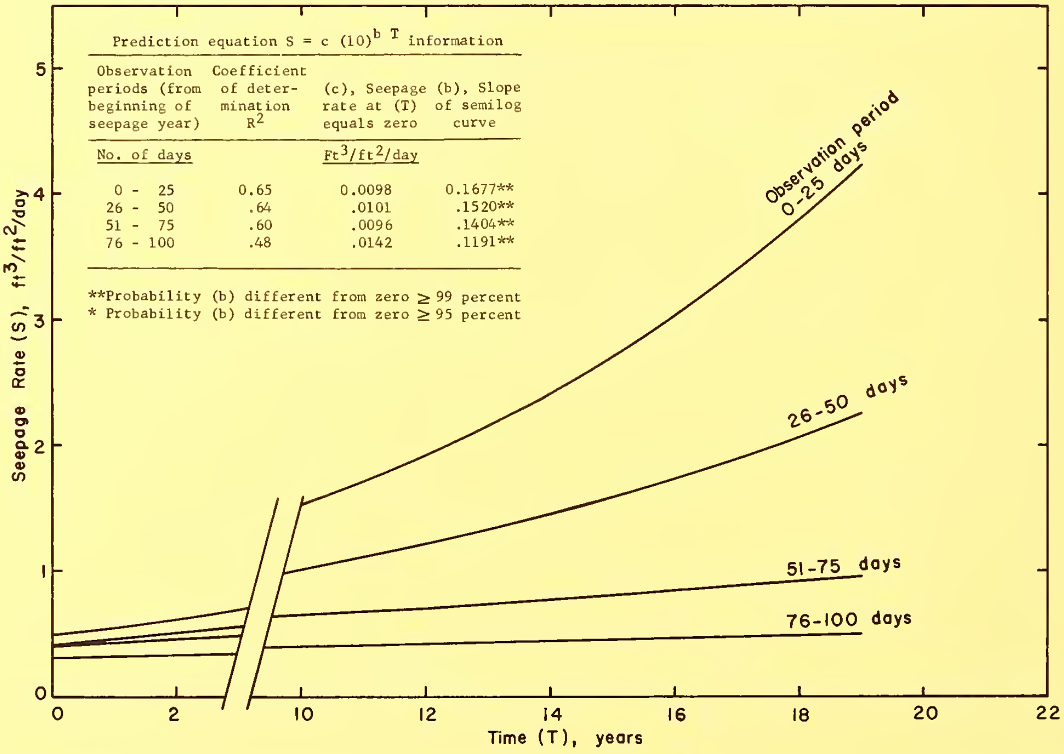


Prediction equation $S = c\ (10)^{b\ T}$ information

Observation periods (from beginning of seepage year)	Coefficient of determination R^2	(c), Seepage rate at (T) equals zero	(b), Slope of semilog curve
No. of days		$Ft^3/ft^2/day$	
0 - 25	0.63	0.0929	0.0906**
26 - 50	.65	.0836	.0860**
51 - 75	.54	.0809	.0735**
76 - 100	.43	.0684	.0670

**Probability (b) different from zero ≥ 99 percent
* Probability (b) different from zero > 95 percent

FIGURE 23. – Relationship between average seepage rate and years of study for Millville silt loam with 5 parts Redmond bentonite in channel C-4.

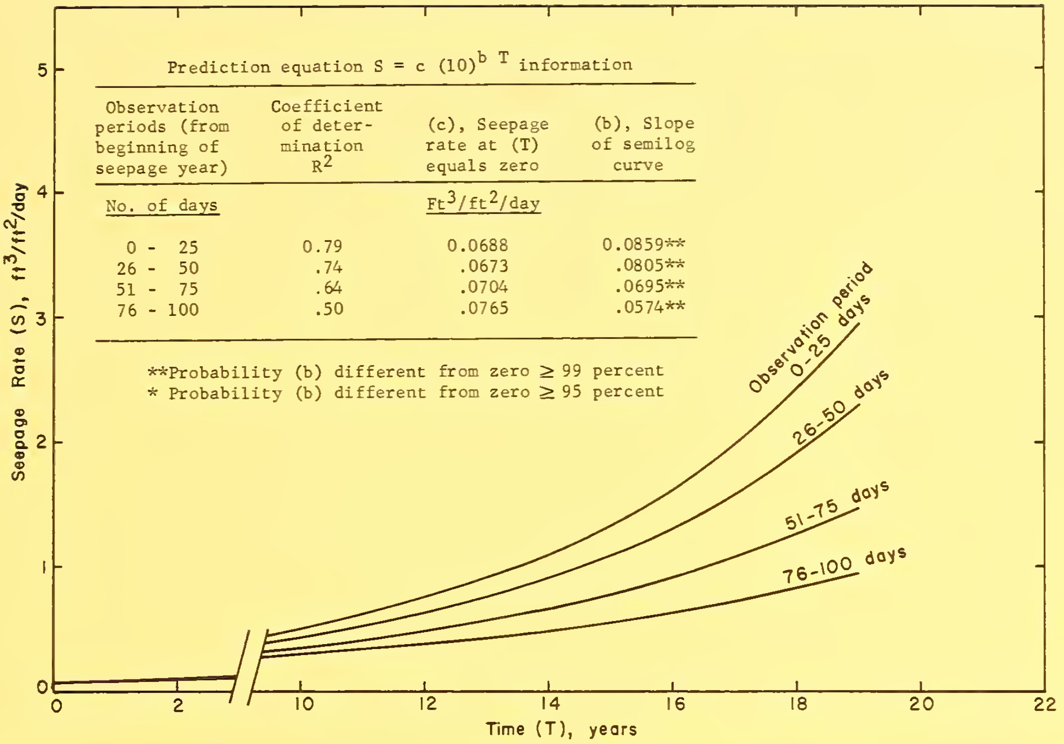


Prediction equation $S = c\ (10)^{b\ T}$ information

Observation periods (from beginning of seepage year)	Coefficient of determination R^2	(c), Seepage rate at (T) equals zero	(b), Slope of semilog curve
No. of days		$Ft^3/ft^2/day$	
0 - 25	0.65	0.0098	0.1677**
26 - 50	.64	.0101	.1520**
51 - 75	.60	.0096	.1404**
76 - 100	.48	.0142	.1191**

**Probability (b) different from zero ≥ 99 percent
* Probability (b) different from zero ≥ 95 percent

FIGURE 24. – Relationship between average seepage rate and years of study for Salt Lake silt loam with 5 parts Redmond bentonite in channel C-5.

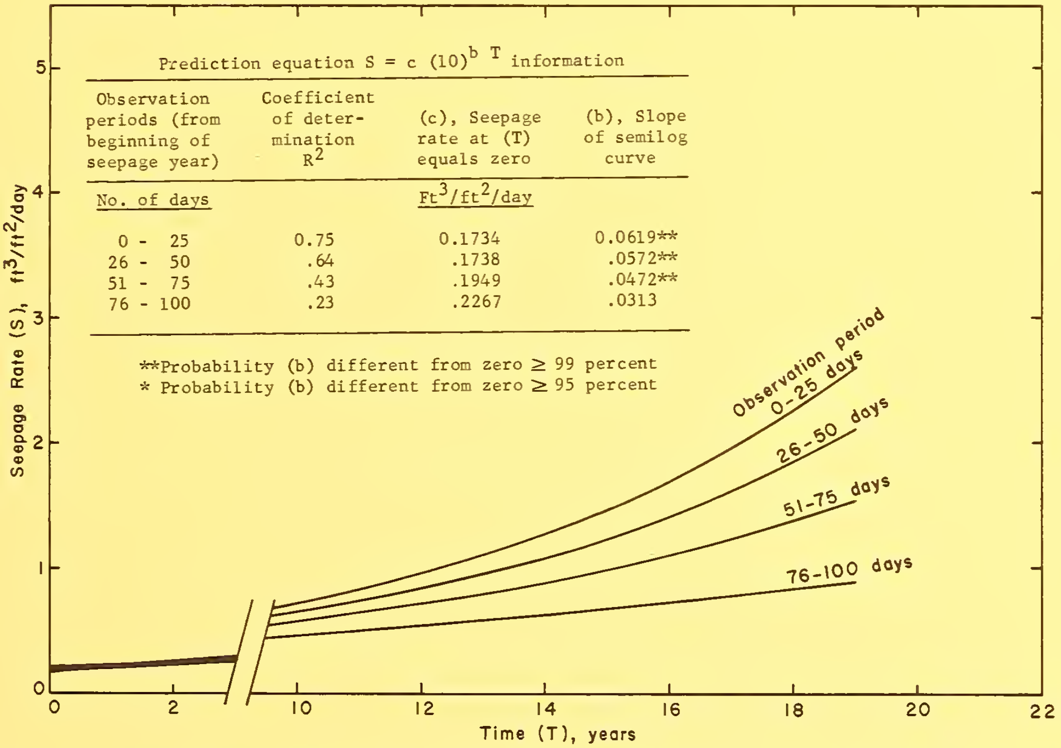


Prediction equation $S = c\ (10)^{b\ T}$ information

Observation periods (from beginning of seepage year)	Coefficient of determination R^2	(c), Seepage rate at (T) equals zero	(b), Slope of semilog curve
No. of days		Ft^3/ft^2/day	
0 - 25	0.79	0.0688	0.0859**
26 - 50	.74	.0673	.0805**
51 - 75	.64	.0704	.0695**
76 - 100	.50	.0765	.0574**

**Probability (b) different from zero ≥ 99 percent
* Probability (b) different from zero ≥ 95 percent

FIGURE 25. — Relationship between average seepage rate and years of study for USBR lining material, silty clay loam in channel C-6.

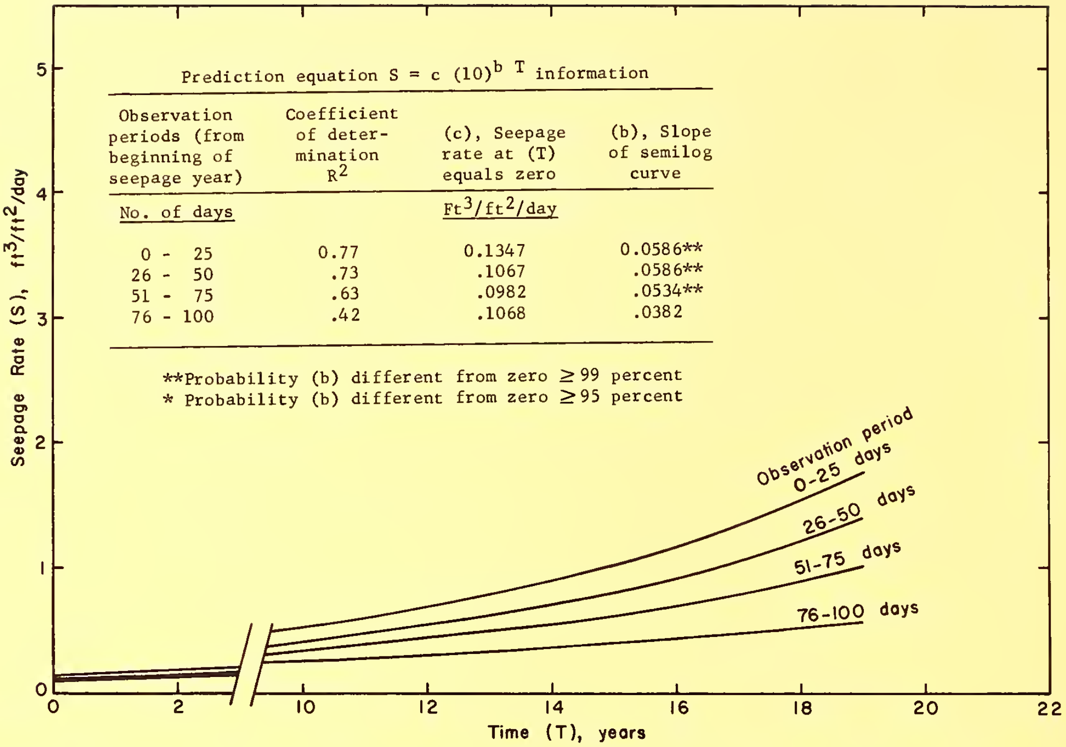


Prediction equation $S = c\ (10)^{b\ T}$ information

Observation periods (from beginning of seepage year)	Coefficient of determination R^2	(c), Seepage rate at (T) equals zero	(b), Slope of semilog curve
No. of days		Ft^3/ft^2/day	
0 - 25	0.75	0.1734	0.0619**
26 - 50	.64	.1738	.0572**
51 - 75	.43	.1949	.0472**
76 - 100	.23	.2267	.0313

**Probability (b) different from zero ≥ 99 percent
* Probability (b) different from zero ≥ 95 percent

FIGURE 26. — Relationship between average seepage rate and years of study for USBR lining material, silt loam in channel C-7.



Prediction equation $S = c\ (10)^{b\ T}$ information

Observation periods (from beginning of seepage year)	Coefficient of determination R^2	(c), Seepage rate at (T) equals zero	(b), Slope of semilog curve
No. of days		$Ft^3/ft^2/day$	
0 - 25	0.77	0.1347	0.0586**
26 - 50	.73	.1067	.0586**
51 - 75	.63	.0982	.0534**
76 - 100	.42	.1068	.0382

**Probability (b) different from zero ≥ 99 percent
* Probability (b) different from zero ≥ 95 percent

FIGURE 27. — Relationship between average seepage rate and years of study for USBR lining material, clay loam in channel C-8.

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