PERFORMANCE OF SOME CANAL AND DUGOUT LININGS ON THE CANADIAN PRAIRIES *

by

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INTRODUCTION

The control of seepage from irrigation canals and dugouts to conserve water and to protect arable lands is an important consideration on the Canadian Prairies. Seepage from unlined irrigation conveyance systems and dugouts wastes valuable water, and often causes adjacent lands to be unproductive because of waterlogging and salt accumulation. This may necessitate the construction of expensive drainage systems for reclamation.

One way to save water and reduce seepage is to make certain that conveyance systems and storage reservoirs are as watertight as it is economically feasible to make them. Lining with relatively impervious materials seems best to meet this requirement.

In the early 1950s the Prairie Farm Rehabilitation Administration (PFRA) became increasingly concerned about water losses from canals and dugouts and the damage caused by seepage to agricultural lands and other property. The Soil Mechanics Division of the PFRA was given the responsibility of studying and reporting on the suitability of canal linings previously installed by the PFRA. At the same time, the Drainage Division of the PFRA was to conduct studies on water loss from existing canals, to recommend where linings should be placed, and to evaluate their effectiveness.

Progress reports (1, 2, 3) on the studies were issued from time to time. The first includes reports on all linings installed by the PFRA before December 1950. The second describes and discusses linings installed from December 1951, and includes a brief summary of observations on the performance of linings placed prior to December 1951. The third gives considerable detail on linings installed from December 1951 to December 1956, and includes observations on the performance of most of the other linings installed by the PFRA since the experimental canal and dugout lining program began. The program has been inactive since 1956 and no further reports have been issued.

This paper reports on the effectiveness and permanence of particular lining materials, some of which are included in the original program and others that have been installed in the interim.

MATERIALS AND METHODS

The lining materials evaluated are compacted earth, asphalt, concrete, and plastics. They represent the types of linings most commonly placed in canals and dugouts in recent years. In studying such linings the three major considerations were watertightness, durability, and the initial costs. Watertightness and cost are easily determined but the durability of these linings is still questionable, particularly under the severe climatic conditions encountered on the Canadian Prairies.

The rate of seepage from a canal was determined by the ponding method in which a section of canal is isolated by watertight checks at both ends and the section filled with water. With no inflow or outflow the rate of water loss from either a ponded section of canal or a dugout during any given period can be measured by staff gauges, with correction being made for evaporation losses. With data on the amount of drop in water level and on the dimensions of the ponded section, the seepage loss in cubic feet (f^3) per square foot (f^2) of wetted area per 24 hours may be computed. Measurement of the drop in level of the water surface in feet per 24 hours was used to express the rate of seepage. Experience has shown that the water surface drop per 24 hours approximates the calculated loss in ft^3/ft^2 per 24 hours.

Exposed black polyethylene plastic linings have been used temporarily on the Prairies for specific purposes, but because they were not considered to be permanent installations data on them have not been included in table IV. Black polyethylene plastic linings were first installed at Swift Current projects in 1955 to reduce seepage in areas where water losses were excessive; in some cases they replaced compacted earth linings. Earlier installations used 8-mil plastic but more recently 6-mil plastic has been used. Plastic linings used were the required width for all small- and medium-size canals so that only one transverse field joint was needed for each folded section of the lining ranging in length from 100 to 200 feet. The standard installation practice allowed 1 foot of freeboard above the full supply level (FSL) and another 1 to 1½ feet of the lining was required on both banks for anchoring. This was accomplished by excavating a narrow ditch about 1 foot above the FSL, and burying the outside edges of the plastic sheet in the ditch bank to prevent the plastic from sliding down the slope. Ditch banks were previously graded to a slope not exceeding 3 to 1, all sharp objects were removed by raking, and the finished surface was rolled smooth. The linings were covered either with the material excavated from the ditch or with sand and gravel hauled to the site. The exposed gravel surface provided better erosion control, but was more costly because of the transportation expense (figure 3).

Data on a large number of linings were collected, but only those that contain seepage or cost figures are presented (tables I to IV).

RESULTS AND DISCUSSION

Compacted Earth

All linings were installed in canals at locations where seepage rates had been high and saline and alkaline conditions had developed below the canals. Most of these lined sections passed through sand and gravel lenses mixed with less permeable materials. Seepage losses from canals lined with compacted earth on the Bow River, Eastend, Maple Creek, and Swift Current projects are presented in table I.

The ponding tests after the completion of lining showed that seepage was reduced to a low rate in all cases studied. There is a gradual increase in seepage rates with time, as measured in the Eastend "G" lateral which was losing water at a rather high rate after 5 years. The Swift Current main canal lining became more permeable each year after the lining was completed and after 10 years had lost its effectiveness.

Compacted earth linings in other canals deteriorated, but several were still moderately effective 10 years after installation. Freezing, thawing, and alternate wet and dry cycles have had a detrimental effect on the compacted earth linings. Each cycle tends to reduce the density of the original compaction (3). Linings less than one foot thick, as installed in the Eastend "G" lateral, became pervious much faster than those one foot or more in thickness.

The unit cost of lining is higher for small ditches than for large canals. The use of standard earth-moving machines employed to line small ditches of less than 8-foot bottom width increased the unit cost considerably. The cost was considerably higher than that of a standard blanket clay lining where the entire transverse section of canal had been filled with impervious material and compacted before the final canal section was excavated. Standard blanket linings consist of clay material that is hauled to the over-excavated canal and compacted on the bottom and the sides to form a watertight lining. The availability of suitable clay and its distance from the canal influenced costs considerably.

The unit cost of lining smaller ditches with compacted earth was as expensive as that of lining them with plastic sheets (tables I and IV). For larger canals the cost of compacted earth linings compared favourably with that of other lining materals. Experience in lining canals with clay has shown that the minimum seepage loss obtained with the best clay lining is less than 0.10 foot per day (4), with an average of 0.20 foot per day, and a maximum 0.50 foot per day (5).

Asphalt Linings

Seepage losses from asphalt lined canals and from a dugout are listed in table II. As all the linings listed have been in place since 1949 to 1951, a fair assessment of their life expectancy was obtained. Asphalt linings were in-

TABLE I. LINING COSTS AND SEEPAGE LOSSES FROM CANALS BEFORE AND AFTER LINING WITH COMPACTED EARTH

Project and structure	Portion of canal	Soil type	Type of lining	Year lined	Cost per sq yard	Seepage losses: rate in ft per day			Remarks
						Before lining	After lining	Seepage losses (No. of years since installation)	
Bow River Lateral F-2	Stn. 36+00 to 83+50	Lean clay and sand	Compacted clay, soil and gravel cover	1955	$1.62	4.39	0.09	0.18 (10)	Effective lining
Bow River Lateral F-2	Stn. 36+00 to 46+50	Lean clay and sand	Compacted clay, soil and gravel cover	1955	$1.62	4.00	0.12	0.18 (10)	Effective lining
Bow River Lateral F-2	Stn. 46+50 to 62+00	Lean clay and sand	Compacted clay, soil and gravel cover	1955	$1.62	9.24	0.08	0.24 (10)	Effective lining
Bow River Lateral F-2	Stn. 62+00 to 83+50	Lean clay and sand	Compacted clay, soil and gravel cover	1955	$1.62	1.09	0.09	0.14 (10)	Effective lining
Eastend "G" Lateral	Stn. 90+77 to 134+00	Clay over sandy subsoil	Compacted clay 8" thick	1951	—	—	0.07	0.47 (5)	Not effective after 5 years
Maple Creek "B" Lateral	Stn. 0+00 to 30+00	Clay and silt over sand and gravel	Compacted clay 20" thick	1952	$1.11	2.00	0.10	0.25 (4)	Effective after 4 years
Maple Creek "C" Lateral	Stn. 0+00 to 12+00	Clay and silt	Compacted clay 12" thick	1952	$0.64	1.16	0.10	0.26 (5)	Effective after 5 years
Maple Creek Main Canal	Stn. 63+00 to 133+00	Clay, silt and sand	Compacted clay 20" thick	1950	$0.67	0.41	0.13	0.24 (6)	Effective after 6 years
Swift Current Main Canal	Stn. 45+00 to 80+00	Clay, silt and sand	Compacted clay 20" thick	1948	$0.18	—	0.11	0.19 (8)	This section was relined with plastic after 15 years

stalled in canals at locations where high seepage losses had occurred. Asphalt-impregnated cotton lining with soil cover was not satisfactory even immediately after installation, and it disintegrated completely after a few years. This lining was not installed according to manufacturer's directions, compliance with which would have increased the unit cost to over $2.00 per square yard (1). Lining in the Melfort dugout was similarly not effective in controlling seepage. Tree roots and sloughing banks have been suggested as reasons for failure of the linings.

The other linings listed in table II were still in use. Seepage rates have increased with time but were still not excessive. Soil cover on the catalytically blown asphalt modified extremes in surface temperature and, when more than 6 inches thick, reduced the activity of asphalt - destroying bacteria (3). Asphalt blown on coarse aggregate has proved to be effective. This lining was relatively thick and the surface was well protected by the coarse aggregate. Surface asphalt had disappeared from its upper side but the aggregate was still attached to the lining (figure 1).

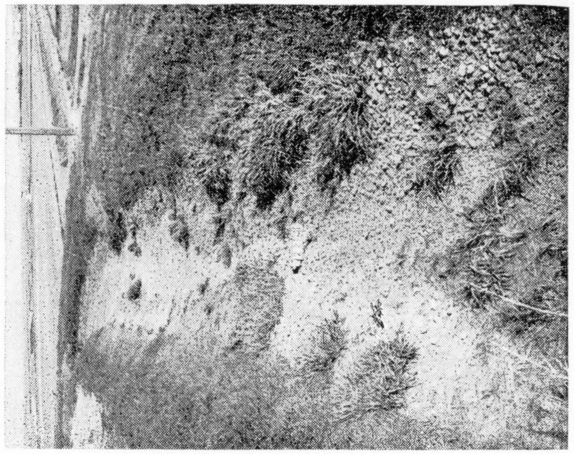

Figure 1. Catalytically blown asphalt on coarse aggregate after 14 years.

Exposed asphalt lining placed directly on the soil was subject to damage by livestock and weathering. Exposed and covered linings on side slopes steeper than 3 to 1 were unstable and subject to sloughing. This was one of the weaknesses of some early installaitons. In several dugouts upward hydrostatic pressure caused the liners to rupture. The asphalt lining of an empty dugout exposed to upward hydrostatic pres-

TABLE II. LINING COSTS AND SEEPAGE LOSSES FROM CANALS AND DUGOUTS BEFORE AND AFTER LINING WITH ASPHALT

Project and structure	Portion of canal	Soil type	Type of lining	Year lined	Cost per sq yard	Seepage losses: rate in ft per day			Remarks
						Before lining	After lining	Seepage losses (No. of years since installation)	
Swift Current Main Canal	Stn. 14+00 to 45+00	Clay, silt and sand	Catalytically blown asphalt 1/8"-1/4" thick covered with 8" of soil	1949	$0.82	0.22	0.06	0.12 (7)	Effective after 16 years
Swift Current Main Canal	Stn. 80+00 to 104+82	Clay, silt and sand	Catalytically blown asphalt 1/8" thick covered with 8" of soil	1950	$1.09	0.30	0.03	0.11 (6)	Effective after 15 years
Swift Current "A" Lateral	Stn. 13+00 to 15+74	Silty clay and sand	Asphalt impregnated cotton and soil cover	1950	$1.40	—	0.42	No seepage control	Not effective, lining had decomposed after 5 years
Swift Current "A" Lateral	Stn. 44+00 to 45+64	Silty clay and sand	Catalytically blown asphalt on 1"-2" aggregate, no cover	1951	$2.40	—	0.08	0.17 (14)	Effective after 14 years
Melfort Water Storage Dugout	Melfort Research Station	Sand lenses in clay bottom	Catalytically blown asphalt, no cover	1951	$1.12	high	high	1.6 (2)	Not effective, was relined with plastic

sure, caused by a high water table in the early spring, was ruptured. However, a lining held down by the weight of a protective covering or water is less subject to damage by an upward hydrostatic force.

Concrete Linings

Results of tests with concrete linings (table III) were all obtained from the "A" lateral at the Swift Current Experimental Station. The linings had been installed in 1950 to test the effectiveness of pneumatically applied concrete of different thicknesses, and the effects of reinforcing and air entrainment on the durability of concrete linings (figure 2a). Most of the concrete lined section of the "A" lateral was in a cut, and seepage losses previous to lining were not very great. A lining placed in a canal passing through a cut is subject to more frost heaving because of the difficulty of draining the canal before freeze-up. A 1½-inch thick unreinforced section contained numerous, thick transverse and longitudinal cracks from which weeds grew (figure 2b). Its effect on seepage control was limited.

A 1¼-inch thick reinforced concrete lining contained intermittent longitudinal cracks about 1 foot from the bottom on both sides. There were a few hairline transverse cracks in this section (figure 2c). Seepage rates have increased since 1953 but the lining was still effective in 1965. A 3-inch thick unreinforced section contained ½- to 1-inch wide longitudinal cracks in the middle of both sides. Some top sections of lining had broken off and showed evidence of frost heaving. There were numerous ⅛-inch wide transverse cracks throughout the section but the lining was still controlling seepage. The most effective lining was a 2-inch thick reinforced section (figure 2d). On the south bank small pieces of lining were broken off apparently by cattle but the rest of the lining was in good condition and showed no evidence of cracks or weed growth. Ponding tests showed that the seepage loss was the lowest in this section.

In summary, the presence or absence of reinforcing steel was more important than the thickness of concrete. Air entrainment also appeared to have little influence on the durability of concrete. The reinforced 1¼-inch thick section was in much better condition than the unreinforced 3-inch section which cost almost twice as much as the thinner

TABLE III. LINING COSTS AND SEEPAGE LOSSES FROM SWIFT CURRENT "A" LATERAL AFTER LINING WITH CONCRETE

Project and structure	Portion of canal	Soil type	Type of lining	Year lined	Cost per sq yard	Seepage losses: rate in ft per day			Remarks
						Before lining	After lining	Seepage losses (No. of years since installation)	
Swift Current "A" Lateral	Stn. 3+30 to 4+93	Clay and sand	3" unreinforced shotcrete, air entrained	1950	$8.17	moderate	0.06	0.27 (15)	Moderately effective after 15 years
Swift Current "A" Lateral	Stn. 4+93 to 8+79	Clay and sand	2" shotcrete reinforced with 4" x 4" wire mesh, air entrained	1950	$6.30	moderate	0.06	0.16 (15)	Effective after 15 years
Swift Current "A" Lateral	Stn. 9+25 to 11+15	Clay and sand	1¼" shotcrete reinforced with 4" x 4" wire mesh, no air entrainment	1950	$4.26	moderate	0.20	0.24 (15)	Effective after 15 years
Swift Current "A" Lateral	Stn. 11+15 to 13+00	Clay and sand	1½" unreinforced shotcrete, no air entrainment	1950	$3.41	moderate	0.20	0.34 (15)	Still in service, large cracks, heavy weed growth, lining easily breakable

TABLE IV. LINING COSTS AND SEEPAGE LOSSES BEFORE AND AFTER LINING WITH POLYETHYLENE BLACK PLASTIC

Project and structure	Portion of canal	Soil type	Type of lining	Year lined	Cost per sq yard	Seepage losses: rate in ft per day			Remarks
						Before lining	After lining	Seepage losses (No. of years since installation)	
Bow River "F" Lateral	Stn. 175+00 to 197+25	Loam on sand and gravel	6 mil plastic, soil and gravel cover	1962	$1.40	0.20*	—	0.0025 (3)	Very effective after 3 years
Bow River F-5 Lateral	Stn. 11+00 to 28+74	Loam on sand and gravel	6 mil plastic, soil and gravel cover	1962	$1.40	2.06	—	0.021 (4)	Very effective after 4 years
Bow River F-5 Lateral	Stn. 28+74 to 49+00	Loam on sand and gravel	6 mil plastic, soil and gravel cover	1962	$1.40	2.03	—	0.16 (4)	Effective lining after 4 years
Swift Current Main Canal	Stn. 45+00 to 80+00	Clay, silt and sand	6 mil plastic, 12" sand and gravel cover	1963	$0.99	high	—	No evidence of seepage 2 years later	Effective lining
Eastend "B" Lateral	Stn. 195+55 to 248+57 and 147+00 to 153+00	Clay, sand and gravel	6 mil plastic sand and gravel cover	1964	$0.67	high	—	No evidence of seepage 2 years later	Effective lining
Bow River Substation Dugout	SE 4-13-16-W4	Loam on sand and gravel	8 mil plastic soil and gravel cover	1956		—	0.016	0.011 (9)	Effective after 9 years
Bow River Grover Dugout	SW 3-13-16-W4	Permeable top soil on clay	8 mil plastic soil and gravel cover	1955	$0.67	—	0.015	0.013 (10)	Effective after 10 years
Outlook Pre-development Farm		Loam with sandy subsoil	8 mil plastic, soil cover	1955	$0.48	high	—	Lining ruptured after 2 years	Original side slopes were too steep. Slopes were flattened and a new lining was placed 10 years later

*10 years before the lining was installed.

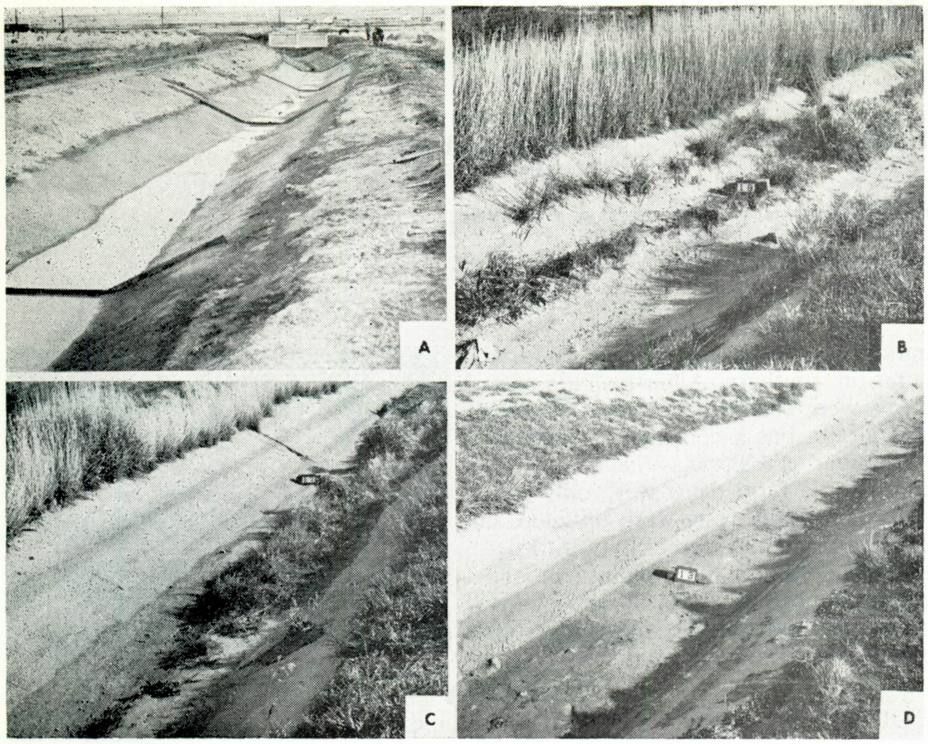

Figure 2. A—Shotcrete lining completed in 1950. Unreinforced 1½-inch shotcrete lining after 15 years. C—Reinforced 1¼-inch shotcrete lining after 15 years. D—Reinforced 2-inch shotcrete lining after 15 years.

reinforced section. Therefore, there were definite economic advantages in using reinforced concrete canal linings at Swift Current.

Plastic Linings

Data on plastic linings (table IV) were obtained from the Bow River project in Alberta, and from the Swift Current and Eastend projects in Saskatchewan.

All listed linings except the one used in the original Outlook Predevelopment Farm dugout, effectively controlled seepage losses. The lining in the Outlook dugout was damaged by the sloughing of side slopes and a new lining was installed after the side slopes were changed.

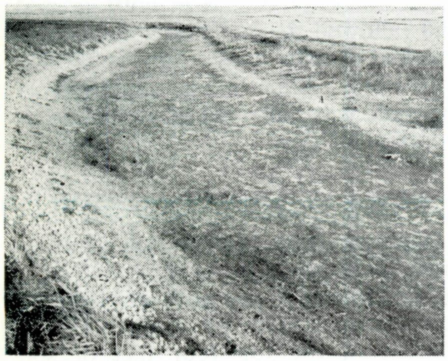

Figure 3. Swift Current main irrigation canal 2 years after 6 mil plastic was installed and covered with 12 inches of sand and gravel.

The majority of plastic linings have been performing well. The life expectancy of covered black polyethylene plastic is estimated to be 20 to 30 years. Where seepage rates have increased since installation, they have been traced to damage to the plastic lining caused either by animals or unstable side slopes. The cost of lining smaller canals with plastic compared favourably with that of compacted earth linings and the plastic lining appears to be more durable. Where local soil was suitable for covering the plastic lining, the unit cost was the lowest of any lining.

SUMMARY

The best seepage control was recorded with black polyethylene plastic linings where the water loss was between 0.0025 and 0.16 foot per day. Asphalt and concrete linings followed and were from 0.06 to 0.19 and from 0.06 to 0.34 feet per day, respectively. Compacted earth linings were the least watertight in this group with losses from 0.08 to 0.47 feet per day. Concrete linings were most costly, followed by asphalt, plastic and compacted earth.

The durability of several linings was obviously longer than the 15 to 16-year observation period. The initial good seepage control of compacted earth linings deteriorated relatively quickly and most linings become gradually less effective. Compacted earth linings were in most cases definitely more pervious and had a shorter life span than the others. Frost heaving caused most damage to concrete linings, particularly in unreinforced sections where seepage losses have increased steadily since installation. The earliest plastic lining installations dated back 10 years and since that time no increase in seepage rates has been observed.

Current popularity of plastic linings appears to be well justified, because of their ease of installation, low cost and excellent seepage control.

ACKNOWLEDGEMENTS

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