Water-Energy Grant Application

Cross Valley Canal Extension Lining - Pool No. 8

Appendix 2.3 - USBR Canal Lining Report

R-02-03

CANAL-LINING DEMONSTRATION PROJECT YEAR 10 FINAL REPORT

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U.S. DEPARTMENT OF THE INTERIOR
Bureau of Reclamation

Pacific Northwest Region
Water Conservation Center

Technical Service Center
Civil Engineering Services
Materials Engineering Research Laboratory

EXECUTIVE SUMMARY

Reclamation has constructed 34 canal-lining test sections in 11 irrigation districts in four States to assess durability and effectiveness (seepage reduction) over severe rocky subgrades. The lining materials include combinations of geosynthetics, shotcrete, roller compacted concrete, grout mattresses, soil, elastomeric coatings, and sprayed-in-place foam. Twenty-eight test sections are located in central Oregon, three are in Montana, two are in Idaho, and one is in Oklahoma. Each test section typically covers 15,000 to 30,000 square feet. The test sections now range in age from 1 to 10 years. Preliminary benefit/cost (B/C) ratios have been calculated based on initial construction costs, maintenance costs, durability (service life), and effectiveness (determined by preconstruction and postconstruction ponding tests). The 34 test sections are divided into 4 generic categories as shown in the table below.

Table ES-1.—Test results for the 34 test sections

Type of Lining	Construction Cost ($/ft^2)	Durability (years)	Maintenance Cost ($/ft^2-yr)	Effectiveness at Seepage Reduction (percent)	B/C Ratio
Fluid-applied Membrane	$1.40 - $4.33	10 - 15 yrs	$0.010	90 %	0.2 - 1.5
Concrete alone	$1.92 - $2.33	40 - 60 yrs	$0.005	70 %	3.0 - 3.5
Exposed Geomembrane	$0.78 - $1.53	10 - 25 yrs	$0.010	90 %	1.9 - 3.2
Geomembrane with Concrete Cover	$2.43 - $2.54	40 - 60 yrs	$0.005	95 %	3.5 - 3.7

Each of the lining alternatives offers advantages and disadvantages. The geomembrane with concrete cover seems to offer the best long-term performance.

Fluid-applied membrane – Many of these test sections have failed and have been removed from the study. Most of the problems were related to poor quality control because of adverse weather common to field construction in late fall and early spring. These types of linings may have potential for special niche applications such as lining existing steel flumes or existing concrete channels.

Concrete – Excellent durability, but long-term effectiveness was only 70 percent because of random cracking. Irrigation districts are familiar with concrete, and they can easily perform required maintenance.

Exposed Geomembrane – The effectiveness is excellent (90 percent), but exposed geomembranes are susceptible to mechanical damage from animal traffic, construction equipment, and vandalism. Although exposed geomembranes have the lowest initial construction costs, they have a limited service life (typically 15 to 20 years). Also, exposed geomembranes are often poorly maintained because irrigation districts are unfamiliar with the geomembrane material, and sometimes need special equipment and training to perform even minor repairs.

Concrete with Geomembrane Underliner – The geomembrane underliner provides the water barrier, and the concrete cover protects the geomembrane from mechanical damage and weathering. System effectiveness is estimated at 95 percent. Districts can readily maintain the concrete cover, but they do not have to maintain the geomembrane underliner.

Effectiveness – Ponding tests showed a typical preconstruction seepage rate of about 1.0 foot per day. Postconstruction ponding tests showed effectiveness of 70 to 95 percent for the various lining alternatives.

Maintenance – Over the course of 10 years, maintenance costs have been relatively low for all the lining alternatives. Generally, exposed geomembranes require about twice the maintenance of concrete linings. For all lining alternatives, benefit/cost analysis shows that every $1 spent on maintenance returns $10 in conserved water by increasing effectiveness and design life. Therefore, more emphasis should be placed on maintenance, especially for exposed geomembrane linings.

New Test Sections

The newest test sections have been in service for only 1 to 2 years. While some of these test sections look promising, more time is needed to evaluate them before estimating service lives and benefit-cost ratios. These test sections include:

Wet-applied polyurethane geocomposite
Exposed reinforced metallized polyethylene
Exposed bituminous geomembrane
Exposed white textured HDPE
Exposed EVA geocomposite

Coupon Testing

Six of the exposed geomembrane test sections were sampled for laboratory evaluation. Although many of the exposed geomembranes visually appear to be in excellent condition, the changes in physical properties suggest that many are beginning to degrade. Service life predictions are included in table ES-2.

Table ES-2—Coupon Testing of Exposed Geomembrane test sections

Test Section	Material	Age	Visual Assessment	Physical Property Testing	Service Life Prediction
A-3	80-mil Textured HDPE	10 years	Excellent	Elongation down 90% OIT down 30%	20-25 years
A-4	30-mil PVC with Bonded Geotextile	10 years	Very Good	Tensile up 30% Modulus up 140% Elongation down 70%	10-15 years
A-5	45-mil Hypalon	10 years	Fair to Poor	Tear strength down 60%	10-15 years
A-6	36-mil Hypalon	10 years	Fair	Tear strength down 60%	10-15 years
O-3	45-mil EPDM	2 years	Excellent	Elongation down 30% Tear strength down 50%	15-20 years
O-4	30-mil LLDPE	2 years	Excellent	Tensile down 10% Tear Strength down 10%	10-15 years

construction bids may be somewhat higher, depending on additional items such as mobilization, design costs, additional subgrade preparation, attachment to structures, contingencies, and unlisted items.

In addition to initial construction costs, the 34 test sections are evaluated for durability, maintenance requirements, and effectiveness at reducing seepage. These factors are combined to calculate life cycle costs.

Environmental Assessment of Canal Lining

Seepage from canals may contribute to groundwater and wetlands. The impact on groundwater and wetlands should be assessed prior to canal lining. This assessment may be mandated for projects using federal funding.

Sometimes canal seepage does not return to the river or increase local groundwater. In this case, the canal seepage is lost to beneficial use, and the canal-lining can proceed without further environmental assessment.

More often, canal seepage returns to the river or contributes to local groundwater. Other users may be using this water by diverting from the river or pumping from aquifers. These users may have a legal right to the water leaking from the canal.

Short sections of canal are often lined to mitigate problems associated with canal seepage. These problems often include stability of the canal bank, flooding of nearby houses and basements, and flooding of adjacent farmland removing it from production. In these cases, short sections (typically a few thousand linear feet) of canal are often lined without further environment assessment.

Restoration to Original Condition – Canals that were originally lined with concrete or compacted earth deteriorate over time and experience increased seepage rates. Concrete and compacted earth canal linings have a typical service life of about 50 years. Over time, the concrete cracks, subsides and heaves. Earth linings are gradually removed as the canal is cleaned out each year. A district that over-excavates their canal 1 inch each year, will completely remove a 3-ft compacted clay lining in only 36 years. The water lost to seepage belongs to the canal owner, and it is the owners right to re-line the canal to restore its original condition.

Value of Conserved Water

The B/C analysis uses $50 per acre-ft for the value of the conserved water. This value was selected as a reasonable price for water purchased on the open market. At the low end, farmers typically pay an assessment of $8 to $20 per acre-ft for the water delivered by their irrigation district. Additional water (when available) can usually be purchased for about twice this cost ($15 to $40 per acre-ft). These costs only reflect the costs for building and maintaining the infrastructure and for delivering the water. These costs do reflect the value of the water on the open market. When cities and developers need to purchase water on the open market, they typically pay $100 to $300 per acre-ft, with the higher prices paid in drought years and in areas where water is especially scarce. Based on this range of prices, a value of $50 per acre-ft seemed quite reasonable.

Effectiveness

Canal lining effectiveness is sometimes expressed as an absolute post-construction seepage rate (ft^3/ft^2-day). This study found that effectiveness is better expressed as a percent reduction in seepage, because the final seepage rate is a function of not only the lining material, but also the permeability of the native soils. For instance, let's look at a geomembrane lining with a small defect (hole). If the subgrade is moderately impermeable (fine-grained soils), then little water will seep through this defect. Conversely, if the subgrade is relatively permeable (sands and gravels), then a substantial amount of water will seep through this same defect. However, in both cases, the percent seepage reduction provided by canal lining (in this case, a geomembrane with a small defect) will be similar.

Using this approach, the various test sections have been divided into four broad categories. Linings within each of these categories use similar materials and have similar design lives, similar maintenance requirements, and similar effectiveness at reducing seepage. The effectiveness values were estimated from the ponding tests on the Arnold and North Unit Canals. Estimates of the durability and maintenance requirements were based on 10-year performance and our knowledge of the materials. Durability estimates have been modified slightly from the 7-year report, based on additional performance data. (See table 18.)

Table 18.—Test section results

Type of Lining	Number of Test Sections	Effectiveness (Seepage Reduction)	Durability	Maintenance ($/ft²-yr)
Concrete	6	70 percent	40-60 years	$0.005
Exposed Geomembrane	14	90 percent	10-25 years	$0.010
Fluid-applied Geomembrane	8	90 percent	10-15 years	$0.010
Concrete with Geomembrane Underliner	3	95 percent	40-60 years	$0.005

Concrete—Concrete includes RCC, Shotcrete, and grout-filled mattresses. When new, concrete is initially quite watertight, although concrete does have a measurable permeability. However, within the first couple of years, concrete starts to develop cracks because of shrinkage during curing, and thermal movement (temperature differences between day and night and summer and winter). Furthermore, concrete often continues to crack over time because of subgrade movement. Also, Shotcrete thickness is difficult to control in the field, and holes routinely develop where original Shotcrete thickness was less than 1 inch. The grout-filled mattress has also cracked, especially in areas where it is less than 1 inch thick because of the rocky subgrade. Cracks tend to grow in length and numbers over the years, but so far, have not widened significantly. Also the concrete degrades because of freezing and thawing. All these degradation modes lead to a predicted service life of 40 to 60 years. Ponding tests show an effectiveness (seepage reduction) of 60 to 90 percent and an estimated long-term effectiveness of about 70 percent. Maintenance requirement s are relatively low for concrete, and irrigation district personnel are familiar with concrete and comfortable making the repairs.

CHAPTER 5
BENEFIT/COST ANALYSIS

All the canal-lining alternatives were compared using Benefit/Cost (B/C) analysis. Alternatives with a B/C ratio greater than 1 are economically viable, but alternatives with a B/C ratio less than 1 cannot be justified based on economics. Obviously, the higher the B/C ratio, the better the alternative economically. For instance:

B/C = 10 every dollar invested (cost) returns $10 in benefit
B/C = 1 every dollar invested (cost) returns $1 in benefit
B/C = 0.5 every dollar invested (cost) returns $0.50 in benefit

Benefit—The primary purpose of all the canal-lining alternatives is to conserve irrigation water. Therefore, the primary benefit is the value of the conserved water. For this study, the value of that water is estimated at $50 per acre-foot. District water assessments typically range from $10 to $25 per acre-foot, while water purchased on the open market costs as much as $300 per acre-foot. Secondary benefits are also achieved by canal lining. That is use of adjacent cropland normally flooded by leaking canals and remediation of damage to structures near canals (such as flooded basements) are examples of secondary benefits. However, the value of these secondary benefits is not included in this analysis.

The amount of water conserved by each canal-lining alternative depends on its effectiveness (percent seepage reduction) and the preconstruction seepage rate. For this study, we used a 180-day irrigation season, and a conservative preconstruction seepage rate of 1.0 foot/day (ft^3/ft^2/day). The effectiveness, durability, and maintenance requirements for four generic types of canal linings are listed in table 19.

Cost—The cost of each alternative is calculated as its life-cycle cost ($/ft2-yr). Life-cycle costs are calculated using initial costs, design life (durability), and maintenance costs. Initial costs were taken from tables 2, 3, and 4 in chapter 1 of this report. Durability and Maintenance costs were taken from table 19.

Table 19.—Effectiveness, durability, and maintenance requirements of generic types of canal linings

Type of Lining	Number of Test Sections	Effectiveness (Seepage Reduction)	Durability	Maintenance ($/ft 2-yr)
Concrete	6	70 percent	40-60 years	$0.005
Exposed Geomembrane	14	90 percent	10-25 years	$0.010
Fluid-applied Geomembrane	8	90 percent	10-15 years	$0.010
Concrete with Geomembrane Underliner	3	95 percent	40-60 years	$0.005

Benefit/Cost Ratios—B/C ratios were calculated for each test section and are tabulated in table 20. Sample calculation is shown in appendix E. Many test sections have favorable B/C ratios, and the lining alternatives with the highest B/C ratio include exposed geomembranes, geomembranes with concrete