R-00-01

CANAL-LINING DEMONSTRATION PROJECT 2000 SUPPLEMENTAL REPORT

January 2000

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

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave Blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	January 2000	Final

4. TITLE AND SUBTITLE
Canal-Lining Demonstration Project 2000 Supplemental Report

5. FUNDING NUMBERS

6. AUTHOR(S)
Jay Swihart and Jack Haynes

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Bureau of Reclamation
Technical Service Center
Civil Engineering Service
Materials Engineering Research Laboratory
Denver, Colorado

Pacific Northwest Region
Water Conservation Center
Boise, Idaho

8. PERFORMING ORGANIZATION REPORT NUMBER
R-00-01

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Same

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
DIBR

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Available from the National Technical Information Service, Operations Division, 5285 Port Royal Road, Springfield, Virginia 22161

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The Deschutes Canal-Lining Demonstration Project is a cooperative effort among the Bureau of Reclamation, several irrigation districts, and several geosynthetic lining manufacturers. The purpose of the study is to develop low-cost canal-lining technologies to reduce seepage over severe rocky subgrade conditions. Over the first 7 years, Reclamation constructed 27 alternative canal-lining test sections using combinations of geosynthetics, shotcrete, roller compacted concrete (RCC), grout mattresses, soil, elastomeric coatings, and sprayed-in-place foam. This report documents the construction of two additional test sections using an exposed 45-mil EPDM rubber geomembrane and an exposed 30-mil Linear Low Density Polyethylene (LLDPE) geomembrane. Unit construction costs range from $0.78 to $0.87 per square foot. The test sections will be monitored for maintenance requirements, durability, and effectiveness to calculate Benefit-Cost ratios.

This report also documents seepage studies performed on a RCC-Shotcrete test section. The seepage studies include both full-scale short-term ponding tests and long-term inflow-outflow measurements taken over a 3-year period. The two methods yield similar results, and show that the RCC-Shotcrete lining is 75 to 85 percent effective which agrees well with previous estimates.

14. SUBJECT TERMS
geosynthetic/water conservation/geotextile/geocomposite/geomembrane/ponding tests/Benefit-Cost Analysis/life-cycle costs

15. NUMBER OF PAGES
60

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UL	UL	UL	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

R-00-01

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UNITED STATES DEPARTMENT OF THE INTERIOR ' BUREAU OF RECLAMATION

ACKNOWLEDGMENTS

The authors wish to thank the irrigation districts whose support was essential to the planning and implementation of this project. The Bureau of Reclamation particularly appreciates the support from the boards of directors of the Arnold, North Unit, Tumalo, Ochoco, Juniper Flat, Frenchtown, and Lugert-Altus Irrigation Districts. Water user support consisted of both a financial commitment and the acceptance of the risks involved with using unfamiliar technologies.

The authors wish to acknowledge the various material suppliers and contractors who were willing to participate in the project. In addition to making financial contributions, the participating companies provided invaluable technical support. These companies have also assumed risks by placing their products adjacent to those of their competitors under adverse conditions and often in new applications.

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EXECUTIVE SUMMARY

The Deschutes Canal-Lining Demonstration Project is a cooperative effort among the Bureau of Reclamation, several irrigation districts, and several geosynthetic lining manufacturers. The purpose of the study is to develop low-cost canal-lining technologies to reduce seepage over severe rocky subgrade conditions.

Over the first 7 years, Reclamation constructed 27 alternative canal-lining test sections using combinations of geosynthetics, shotcrete, roller compacted concrete (RCC), grout-filled mattresses, elastomeric coatings, and sprayed-in-place foam. This report documents the construction of two additional test sections in November 1999, and additional seepage studies performed in December 1999.

The two new test sections include exposed 45-mil EPDM rubber, and exposed 30-mil EPDM rubber. Construction costs ranged from $0.78 to $0.87 per square foot. These construction costs are at the low end of all the test sections built to date.

The seepage studies were performed on the RCC-Shotcrete test section in the North Unit Main Canal. The seepage studies include both short-term full-scale ponding tests performed over a 1,400-ft reach of canal, and long-term inflow-outflow measurements taken over a 25-mile reach of canal over a 3-year period. The 3 years of inflow-outflow measurements include 1996 (unlined canal), 1998 (canal invert lined with RCC), and 1999 (canal invert lined with RCC, sideslopes lined with shotcrete). The inflow-outflow measurements show:

1. The unlined seepage rate for the North Unit Canal averages 1.1 ft/day which agrees well with our earlier estimate of 1 ft/day *(Year 7 Report)*. The first 12½ miles of canal has a higher unlined seepage rate (1.5 ft/day), with some isolated areas as high as 20 ft/day.

2. The effectiveness of RCC lining of the invert only is about 30 percent, which agrees well with our earlier estimate of 40 percent effectiveness *(Year 7 Report)*.

3. The fully-lined seepage rate is 0.38 ft/day, which agrees reasonably well with the 1999 ponding test result of 0.6 ft/day.

4. The effectiveness of RCC lining of the invert and shotcrete lining of the sideslopes is about 75 percent, which agrees well with our earlier estimate of 70 percent *(Year 7 Report)*. This effectiveness also agrees well with the 1999 ponding test which shows effectiveness of 80 to 85 percent.

All 29 of the test sections will continue to be monitored for maintenance requirements, durability (life expectancy), and effectiveness (seepage reduction) to calculate Benefit-Cost ratios.

INTRODUCTION

Traditional canal-lining materials typically include compacted earth, reinforced and unreinforced concrete, and (more recently) buried geomembranes. This report is part of an on-going investigation involving alternative canal-lining technologies that are less expensive, easier to construct with limited access, and compatible with severe rocky subgrades. Prior to this report, 27 test sections have been constructed using combinations of geosynthetics, shotcrete, grout-filled mattresses, soil, elastomeric coatings, and sprayed-in-place foam. These test sections now range in age from 1 to 8 years.

This report documents the construction of two new test sections on the Ochoco Irrigation District in November 1999, and additional seepage studies performed on the North Unit Main Canal in December 1999. Both these irrigation districts are located in central Oregon.

All the test sections are being evaluated for initial construction costs, durability, life-cycle costs, effectiveness at reducing seepage, and Cost/Benefit analysis. The unit construction costs for all 29 test sections are included in tables 1 and 2.

Table 1.—Canal lining costs—Arnold and North Unit Test Sections

Section No.	Arnold Irrigation District Description	Lining Material: Geomembrane cost per sq. foot ($)	Lining Material: Geotextile cost per sq. foot ($)	Lining Material: Shotcrete cost per sq. foot ($)	Lining Material: Other cost per sq. foot ($)	Subgrade* Preparation cost per sq. foot ($)	Installation cost per sq. foot ($)	Overhead and profit (%)	Total ($)
A-1	4-mil PE Geocomposite with Shotcrete cover								
	Unreinforced Shotcrete	$0.30		$0.87		$0.26	$0.65	17%	$2.43
	Polyfiber reinforced Shotcrete	$0.30		$0.87	$0.06	$0.26	$0.65	17%	$2.50
A-2	30-mil LLDPE textured geomembrane with 16-oz. geotextile cushion and unreinforced Shotcrete cover	$0.25	$0.12	$0.87		$0.26	$0.65	17%	$2.52
A-3	Exposed 80-mil HDPE textured geomembrane	$0.70	$0.12			$0.26	$0.10	17%	$1.38
A-4	Exposed 30-mil PVC with geotextile UV cover cushion	$0.45	$0.07			$0.26	$0.12	17%	$1.05
A-5	Exposed 45-mil Hypalon with 16-oz. geotextile cushion	$0.45	$0.12			$0.26	$0.12	17%	$1.11
A-6	Exposed 36-mil Hypalon with bonded 8-oz. geotextile cushion	$0.50				$0.26	$0.12	17%	$1.03
A-7	40-mil PVC with 3-inch Grout-Filled Mattress	$0.35		$0.65	$0.45	$0.12	$0.60	17%	$2.54
A-8	3-inch Unreinforced Grout-Filled Mattress			$0.65	$0.45	$0.04	$0.50	17%	$1.92
A-9 and A-10	60-mil LLDPE or HDPE with 12-oz. geotextile cushion and 3-inch Grout-Gilled Mattress on sideslopes only	$0.55	$0.12	$0.21	$0.16	$0.04	$0.45	17%	$1.79
Section No.	**North Unit Irrigation District Description**								
N-1	Spray-applied Polyurethane Foam with Urethane 500/550 protective coating				$2.41	$0.04	$1.25`	17%	$4.33
N-2	Spray-applied Polyurethane Foam with Geothane 5020 protective coating				$2.06	$0.04	$1.25	17%	$3.92
N-3	Tietex Geotextile with Spray-applied Geothane 5020 protective coating		$0.07		$0.90	$0.04	$1.25	17%	$2.64
N-4	Phillips Geotextile with Spray-applied Geothane 5020 protective coating		$0.07		$0.90	$0.04	$1.25	17%	$2.64
N-5	RCC invert + Shotcrete sideslopes	Contract Bid Price							$2.00
N-6	Shotcrete - Steel-Fiber Reinforced								
	50 lbs. per cubic yard			$1.08	$0.22	$0.04	$0.65	17%	$2.33
	25 lbs. per cubic yard			$1.08	$0.11	$0.04	$0.65	17%	$2.20
N-7 and N-8	Shotcrete Polyfiber Reinforced								
	3 lbs. per cubic yard			$1.08	$0.12	$0.04	$0.65	17%	$2.21
	1-1/2 lbs. per cubic yard			$1.08	$0.06	$0.04	$0.65	17%	$2.14
N-9	Unreinforced Shotcrete			$1.08		$0.04	$0.65	17%	$2.07

* Costs based on minimal, moderate, and extensive subgrade preparation (Swihart et al., May 1994).

Table 2.—Canal lining costs—Tumalo, Lugert-Altus, Juniper Flat, Ochoco, and Frenchtown Test Sections

Section No.	Description	Lining Material				Subgrade Preparation cost per sq. foot ($)	Installation cost per sq. foot ($)	Overhead and Profit (%)	Total per sq. foot ($)
		Geomembrane cost per sq. foot ($)	Geotextile cost per sq. foot ($)	Shotcrete cost per sq. foot ($)	Other Cost per sq. foot ($)				
T-1	Liquid Boot over an existing concrete flume	$1.20				$0.15	$0.10	17%	$1.70
T-2	Liquid Boot over a sandblasted steel flume	$1.00				$0.15	$0.10	17%	$2.16
T-3	Liquid Boot over a broomed steel flume	$1.00				$0.10	$0.10	17%	$1.40
L-1	Exposed 160-mil Teranap	$0.95				$0.26	$0.10	17%	$1.53
J-1	Exposed 160-mil Teranap	$0.95				$0.26	$0.10	17%	$1.53
O-1a	Covered GCL - Bentomat DN	$0.29				$0.26	$0.15	17%	$0.82
O-1b	Covered GCL - Bentomat CL	$0.33				$0.26	$0.15	17%	$0.87
O-2a	Exposed GCL - Bentomat DN	$0.29				$0.26	$0.10	17%	$0.76
O-2b	Exposed GCL - Bentomat CL	$0.33				$0.26	$0.10	17%	$0.81
O-3a	Exposed 45-mil EPDM PondGard with 8-oz geotextile on sideslopes only	$0.30	0.06			$0.26	$0.10	17%	$0.84
O-3b	Exposed 45-mil EPDM PondGard with 8-oz geotextile on sideslopes only and covered invert	$0.30	0.06			$0.26	$0.12	17%	$0.87
O-4	Exposed 30-mil LLDPE EnviroLiner with 8-oz geotextile on sideslopes only	$0.25	0.06			$0.26	$0.10	17%	$0.78
F-1	Exposed 45-mil PP over a broomed steel flume	$0.40			$0.12	$0.10	$0.15	17%	$0.90

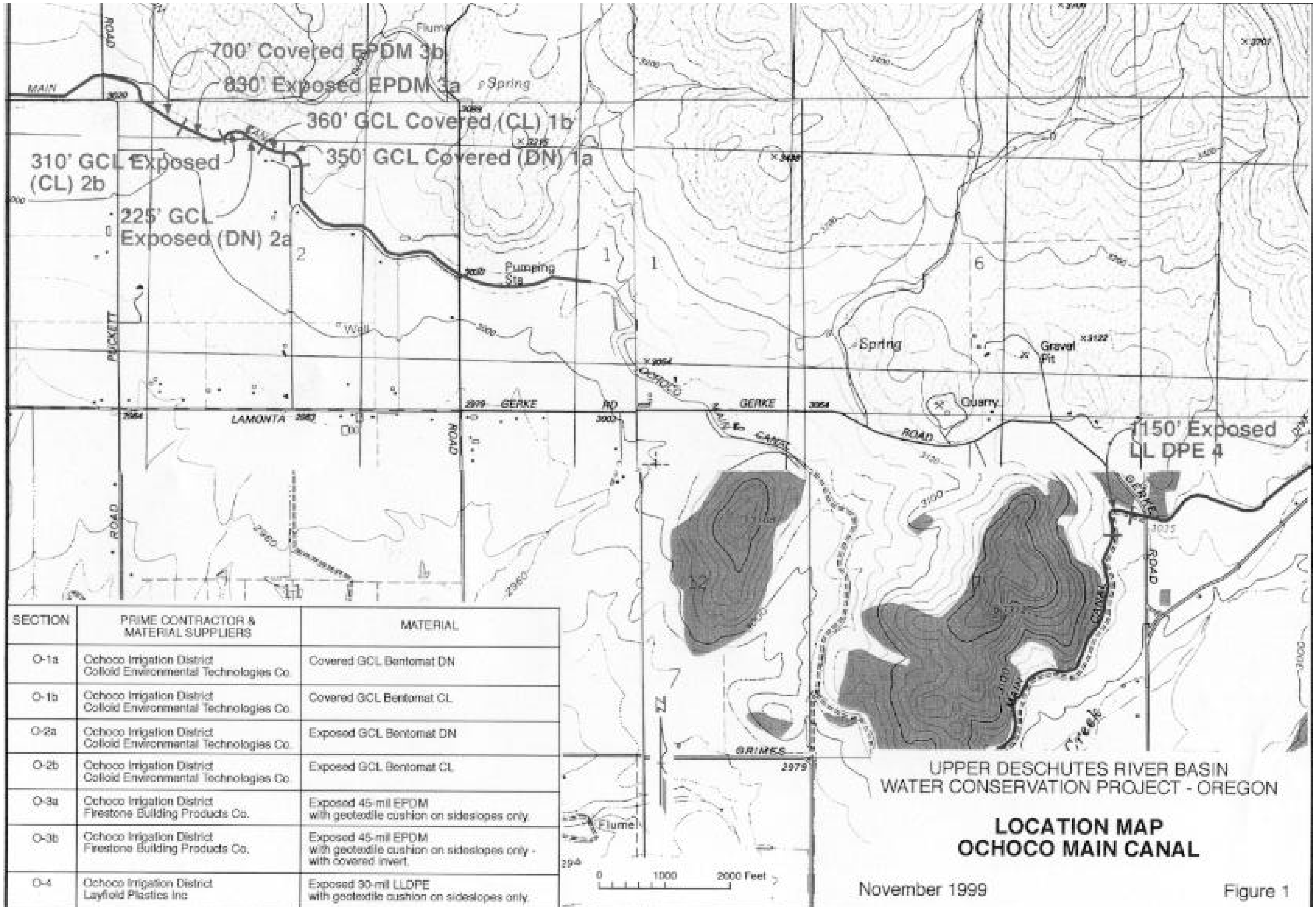
NEW TEST SECTIONS

Ochoco Irrigation District

Background.—The Ochoco Irrigation District (OID) was organized in 1916 and is located near the city of Prineville in central Oregon.

The district provides irrigation water for 750 water users irrigating 20,150 acres. The principal sources of water are Ochoco Reservoir on Ochoco Creek, and Prineville Reservoir on the Crooked River. Ochoco Reservoir is formed by Ochoco Dam located 5½ miles east of the city of Prineville, while Prineville Reservoir is formed by Bowman (Prineville) Dam. Ochoco Dam was originally constructed in 1918-1921 using private capital, and was then rehabilitated by Reclamation in 1949-1950 and again in 1995-1996. Additional project features include 50 miles of main canal, 24 miles of open laterals, 36 miles of delivery pipeline, and 16 miles of drains (of which 12 miles are piped). Almost all of the canals and laterals are unlined, with the exception of the first 1.75 miles of the concrete-lined Ochoco Feed Canal (immediately downstream of Ochoco Dam) followed by 5½ miles of clay- and bentonite-lined canal. Typically, canals flow on a grade of 1 foot fall per 1,000 feet of length.

The 4 test sections are located on the Main Canal north and northwest of the city of Prineville. Test Sections O-1, O-2, and O-3 are located 6 miles northwest of Prineville, while Test Section O-4 is 3 miles north town (see Figure 1). Test Sections O-1 and O-2 were constructed in April 1999 (see *"Year 7 Report"*), while Test Sections O-3 and O-4 were constructed in November 1999 and are addressed in this report. The maximum flow through the test section area is 80 to 100 cfs at a depth of about 4 feet. The site for the test section was selected based on discussions with the District. The test areas have long been a problem with high seepage, flooding adjacent property including some basements. Ponding tests in the immediate area of the test section will be performed in the near future to determine pre- and postconstruction seepage rates.



SECTION	PRIME CONTRACTOR & MATERIAL SUPPLIERS	MATERIAL
O-1a	Ochoco Irrigation District Colloid Environmental Technologies Co.	Covered GCL Bentomat DN
O-1b	Ochoco Irrigation District Colloid Environmental Technologies Co.	Covered GCL Bentomat CL
O-2a	Ochoco Irrigation District Colloid Environmental Technologies Co.	Exposed GCL Bentomat DN
O-2b	Ochoco Irrigation District Colloid Environmental Technologies Co.	Exposed GCL Bentomat CL
O-3a	Ochoco Irrigation District Firestone Building Products Co.	Exposed 45-mil EPDM with geotextile cushion on sideslopes only.
O-3b	Ochoco Irrigation District Firestone Building Products Co.	Exposed 45-mil EPDM with geotextile cushion on sideslopes only - with covered invert.
O-4	Ochoco Irrigation District Layfield Plastics Inc	Exposed 30-mil LLDPE with geotextile cushion on sideslopes only.

UPPER DESCHUTES RIVER BASIN
WATER CONSERVATION PROJECT - OREGON

LOCATION MAP
OCHOCO MAIN CANAL

November 1999

Figure 1

Test Section O-3.—

Material:	Exposed 45-mil EPDM Geomembrane with Geotextile Cushion on Sideslopes Only
Date installed:	November 1999
Location:	Ochoco Irrigation District - 6 miles northwest of Prineville (1530 linear feet; 63,000 square feet)
Description:	Firestone PondGard is 45-mil unreinforced EPDM (Ethylene Propylene Diene Monomer) Rubber. The geotextile cushion on the sideslopes is 8-oz needle-punched nonwoven (LP-8) supplied by Layfield Plastics. Product data sheets are included in Appendix A-1.
Prime Contractor:	Ochoco Irrigation District
Material Suppliers:	Firestone Layfield Plastics
Subgrade prep:	Ochoco personnel performed extensive subgrade preparation by removing vegetation from the canal, restoring the 1½:1 sideslopes (approximate), and cutting the V-notch anchor trench. The cost for subgrade preparation is estimated at $0.26 per square foot, which was chosen to match the subgrade preparation costs used on the previous test sections. The finished canal prism measures 40 to 45 feet across, plus a 1-ft anchor trench on each bank.
Construction:	The EPDM geomembrane was installed directly downstream of the GCL test sections (O-1 and O-2), where water leaking from the canal was saturating an adjacent field. The EPDM membrane is manufactured in 10-ft wide rolls, and the rolls are then fabricated into 50-ft by 200-ft panels, with the factory seams (heat vulcanized) running in the shorter dimension. Eight panels were delivered to the jobsite. Other size panels are available. The panels were accordion folded at the factory in the 50-ft direction. The panel was then rolled onto a 10-ft wide core. Each rolled panel weighs about 3000 pounds. Panels of GCL were shingled in the downstream direction (upstream over downstream). Because of hard mineral deposits (locally referred to as Ochoco Tuff), the sideslopes were first covered with an 8-oz geotextile cushion, before lining the entire canal prism with the EPDM geomembrane (see Appendix B for discussion of local geology). The geotextile was installed by hand by a 4-man crew. The EPDM panels were then unrolled (by hand) along the canal access road for 200 feet. The 19-man crew than unfolded the panels into the canal prism to their full 50-ft width. The crew then pulled the panel up the far canal bank. After final positioning, the excess width (typically 5 to 8 feet) was trimmed and discarded. On canal bends, the panels were cut in half to 100-ft length. These half-size panels were much easier to handle and to fit to the canal. Adjacent panels were overlapped 6-12 inches, shingled downstream, and seamed with a special EPDM adhesive and tape provided by the membrane manufacturer. Finally, the EPDM membrane was secured by backfilling the anchor trench.

The first 830 linear feet of EPDM were left exposed, while the lower 700 linear feet were covered with 4 to 6 inches of soil in the invert only. The invert of the upper 830 linear feet is expected to become covered with sediment within a couple of years.

Seams - The factory vulcanized seams demonstrated excellent shear and peel strength. The EPDM tape field seams demonstrated relatively low strength (about 15 lbs/inch shear and 8 lbs/inch peel), however this seam strength is probably adequate for this application. The EPDM tape also worked equally well on the Linear Low Density Polyethylene (LLDPE) geomembrane from test section O-4. The complete test results are tabulated in Appendix C.

Difficulties: A very large crew is needed to unfold and position the 200-ft panels. Seaming was very slow because of the 1½:1 sideslopes and because of irregularities in the prepared subgrade.

Unit Cost Estimate: Exposed EPDM = $0.84 per square foot
($0.30 EPDM + 0.06 cushion + 0.26 subgrade + 0.10 installation + 17% OH & profit)

Exposed EPDM (with covered invert) = $0.87 per square foot
($0.30 GCL + 0.06 cushion + 0.26 subgrade + 0.10 installation + 0.02 burial + 17% OH & profit)

Advantages: Because of the large panels and good canal access, installation was fast and simple. Irrigation districts can install this material with their own forces, which allows flexibility in the construction schedule to accommodate bad weather and fluctuating workload. Including a little hands-on training the first morning, this inexperienced crew installed 63,000 square feet (7½ panels) in 1½ days. By using their own equipment and labor, the district was able to install at significantly less cost compared to hiring a contractor. Seaming is easy and requires no special equipment. EPDM rubber is quite flexible and conforms readily to subgrade irregularities. Panels can also be installed across the canal and cut to fit, which would increase the number of field seams, but minimize waste. These smaller panels would be easier to handle, but the factory seams would be under stress on the sideslopes.

Disadvantages: The manufacturer claims average seaming speeds of 15 feet per minute on flat slopes with smooth subgrades. Because of our 1½:1 sideslopes and slightly irregular subgrade, our 3-man crew averaged only about 1 foot per minute. Also the seaming materials are expensive, reportedly adding $0.02 to 0.03 per square foot. The 200-ft panels were difficult to deploy and position even with our 19-man crew. Future installations might consider special ordering panels that are accordion folded in the 200-ft dimension, so they can be unfolded down the canal using mechanized equipment. Panels can also be installed across the canal; however, this orientation would place the factory seams in tension on the sideslopes. Exposed EPDM will be subject to environmental as well mechanical damage.

Material Note: EPDM liner delivered to the jobsite was labeled “RubberGard” which is the Firestone trade name for the roofing industry. For the canal and reservoir industry, Firestone will market this material as “PondGard”. The only difference is that PondGard uses a fish-friendly curing package, and can be used in landscaping ponds with ornamental fish.

Photographs:	1 through 22

Photograph 1.—The Ochoco Irrigation District prepared the subgrade by removing vegetation, restoring the 1½:1 sideslopes, and cutting the V-notch anchor trench.

Photograph 2.—Eight rolls of EPDM geomembrane (50-ft by 200-ft) were delivered to the jobsite; Rolls of geotextile cushion (foreground) measure 15-ft by 300-ft

Photograph 3.—Deposits of Ochoco “Tuff” are most prevalent on the sideslopes.

Photograph 4.—Geotextile is unrolled along the canal bank and pulled into position

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Photograph 5.—Geotextile covering the sideslopes;
Manufacturer did not require geotextile in the invert.

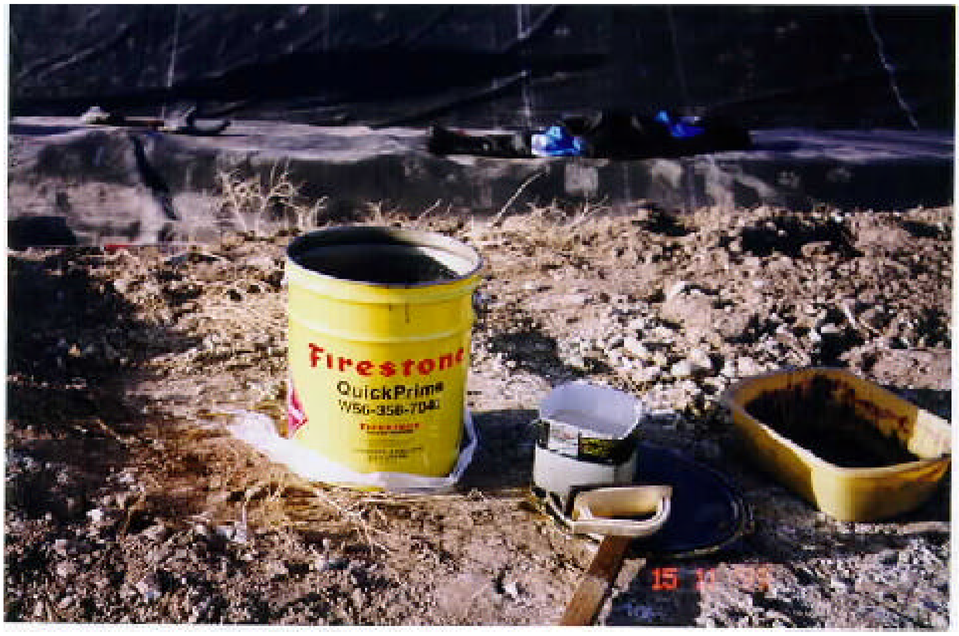
Photograph 6.—Crew unrolls the EPDM geomembrane along the canal bank.

Photograph 7.—Crew unfolds the EPDM membrane into the canal prism.

Photograph 8.—Crew pulls the EPDM membrane up the far slope.

Photograph 9.—After final positioning, excess material is trimmed and discarded.
Note that the factory seams run across the canal (perpendicular to flow).

Photograph 10.—Adjacent panels are shingled downstream, and primed on both surfaces.



Photograph 11.—Firestone “Quick-Prime” acts as cleaner, primer, and adhesive.

Photograph 12.—After the primer has flashed (dried), the two panels are placed in contact and sealed by rolling.

Photograph 13.—The top surface of the seam is then primed and covered with 6-inch-wide EPDM tape.

Photograph 14.—The tape is then rolled to seal the seam and remove any wrinkles.

Photograph 15.—EPDM tape and primer are also used for patches.

Photograph 16.—Lot numbers are printed onto the membrane at the factory. This roll was manufacturer the 88th day of 1999 (second shift). The liner thickness is 0.0454 inches.

Photograph 17.—Trackhoe excavates cut-off trench at the upstream transition.

Photograph 18.—Cut-off trench is excavated around concrete turnout.

Photograph 19.—Grader backfills the anchor trench.

Photograph 20.—Several deer entered the canal overnight with no damage to the liner. Also note the close-up of the vulcanized factory seam on the right.

Photograph 21.—Trackhoe places 4 to 6 inches of soil cover in the invert on the downstream half of the test section. Upstream half is left entirely exposed. Note the rain water that has collected in the invert overnight.

Photograph 22.—Completed test section (upstream half without soil cover in invert).

Test Section O-4.—

Material:	Exposed 30-mil LLDPE Geomembrane with Geotextile Cushion on Sideslopes Only
Date installed:	November 1999
Location:	Ochoco Irrigation District - 3 Miles north of Prineville (1150 linear feet; 48,000 square feet)
Description:	Layfield Plastics Enviro Liner is 30-mil LLDPE. The geotextile cushion on the sideslopes is 8-oz needle-punched nonwoven (LP-8) supplied by Layfield Plastics. Product data sheets are included in Appendix A-2.
Prime Contractor:	Ochoco Irrigation District
Material Suppliers:	Layfield Plastics
Subgrade prep:	Ochoco personnel performed extensive subgrade preparation by removing vegetation from the canal, and restoring the 1½:1 sideslopes (approximate). The cost for subgrade preparation is estimated at \$0.26 per square foot, which was chosen to match the subgrade preparation costs used on the earlier Arnold test sections. The finished canal prism measures 40 to 45 feet across, plus a 1-ft anchor trench on each bank.
Construction:	The LLDPE was installed in an area where water leaking from the canal was saturating a field adjacent to canal. The LLDPE membrane is manufactured in 10-ft wide rolls, and the rolls were then specially fabricated into 5 panels to match the canal prism. The panels measured 56- to 60-ft wide and 150- to 350-ft long. The factory seams were wedge welded parallel to the shorter dimension. The panels were according folded at the factory in the longer direction, and then rolled onto a 6-ft wide core. The rolled panels weigh between 2,000 and 4,000 pounds. Panels were shingled in the downstream direction (upstream over downstream). Because of deposits of Ochoco Tuff (see Appendix B for local geology), the sideslopes were first covered with an 8-oz geotextile cushion by a 4-man crew. The entire canal prism was then covered with the LLDPE geomembrane. The LLDPE panels were first unrolled across the canal and pulled up the far bank with a backhoe. The panels were then unfolded down the canal by two backhoes operating on opposite sides of the canal. The larger panels were typically cut down into 100- to 200-ft pieces for final positioning by the 8-man crew. Panels were cut into 50- to 75-ft lengths for fitting around bends in the canal. After final positioning, the excess width (typically 5 to 8 feet) was trimmed and discarded. Adjacent panels were overlapped 2 to 3 feet, shingled downstream, and seamed. Seaming was performed by a certified welder from

Layfield Plastics. Seams were either wedge welded or extrusion welded. Patches were either extrusion welded or hot-air welded. Finally, the LLDPE membrane was secured by backfilling the anchor trench. All the LLDPE membrane will be left exposed.

Seams - The factory wedge-weld seams demonstrated excellent shear and peel strength. Trial field seams (wedge-weld and extrusion-weld) were tested on-site and failed by FTB (film tear bond) indicating good strength. A trial field seam using the EPDM tape from test section O-3 demonstrated relatively low strength (about 13 lbs/inch shear and 8 lbs/inch peel), however this seam strength is probably adequate for this application. The complete test results are tabulated in Appendix C.

Difficulties: Deploying the first panel was quite challenging without the benefit of on-site technical support. A rainstorm during deployment of this first panel delayed final positioning until the next morning. Pumps were then needed to remove an inch of water that had accumulated on the liner overnight. Seaming was very slow because of the 1½:1sideslopes and because of irregularities in the prepared subgrade. Also the 30-mil LLDPE is quite thin and therefore difficult to weld.

Unit Cost Estimate: Exposed LLDPE = $0.78 per square foot
($0.25 LLDPE + 0.06 geotextile cushion + 0.26 subgrade preparation + 0.10 installation + 17% OH & profit)

Advantages: Because of the large panels and good canal access, installation was quite fast. Irrigation districts can install this material with their own forces, which allows flexibility in the construction schedule to accommodate bad weather and fluctuating workload. Including time spent figuring out how to unroll, unfold, and deploy that first afternoon, this inexperienced crew installed 48,000 square feet in 2 days. By using their own equipment and labor, the district was able to install at significantly less cost compared to hiring a contractor.

Disadvantages: Seaming requires special equipment and a qualified welder from the lining manufacturer. Labor charges for the welder were $725 per day plus mobilization/demobilization. Seaming cannot be performed during periods of rain. The 30-mil LLDPE is quite thin and therefore difficult to weld. The wedge welder repeatedly melted through the liner, requiring numerous patches. Seaming was quite slow, averaging about 1 foot per minute. LLDPE cannot be patched in the field without specialized equipment and a certified welding technician. Exposed LLDPE will be subject to environmental as well mechanical damage.

Photographs: 1 through 18

Photograph 1.—Unlined canal prior to construction of the LLDPE test section.

Photograph 2.—The Ochoco Irrigation District prepared the subgrade by removing vegetation, restoring the1½:1 sideslopes, and cutting the V-notch anchor trench.

Photograph 3.—The LLDPE was delivered to the jobsite in 5 large panels (4 shown) that were accordion folded and rolled onto cores.

Photograph 4.—forklift positions the first panel and unrolls it into the panel prism**.**

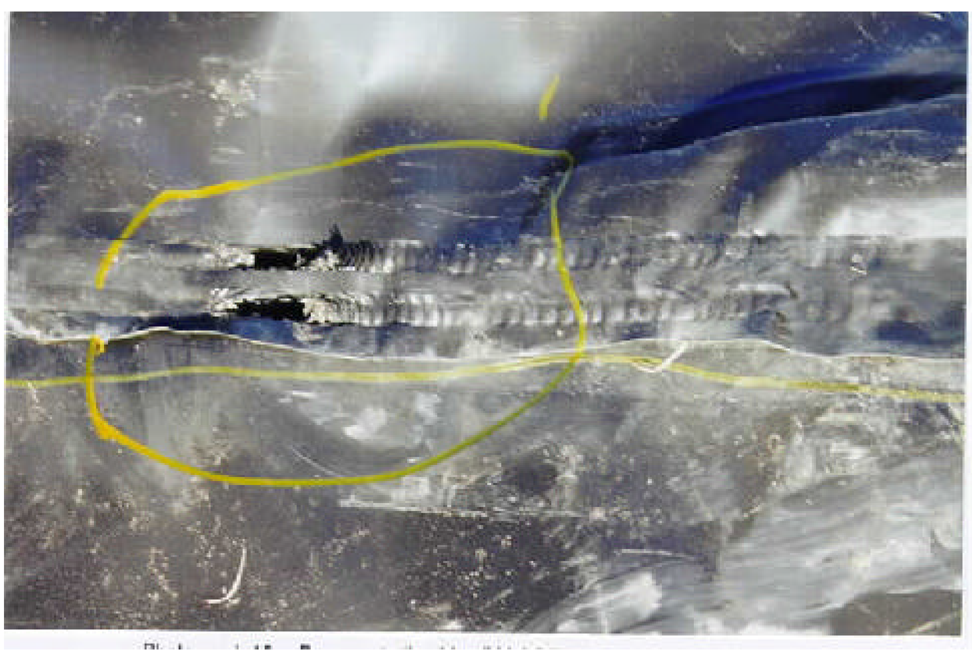
Photograph 5.—Forklift pulls (unrolls) the panel up the opposite bank.

Photograph 6.—Small panels (up to 100 feet long) can be unfolded by hand with an 8-man crew. Note the geotextile cushion on the sideslopes.

Photograph 7.—Larger panes (up to 250 feet long) are unfolded by two backhoes operating on opposite banks.

Photograph 8.—Large C-clamps and 2 x 4's are used to grip the liner. Chains connect the liner to the backhoe.

Photograph 9.—Panels are shingled downstream and wedge-welded by the membrane manufacturer's certified welding technician.



Photograph 10.—Damage to the 30-mil LLDPE caused by the wedge welder. Thicker liners are less easily damaged and easier to weld.

Photograph 11.—Welding technician patches the liner with hot-air welder.

Photograph 12.—Finished patch is identified with date, time, liner manufacturer, technician initials, and patch number.

Photograph 13.—Welding technician fabricates a “boot” around
12-inch diameter pipe penetration with extrusion welder.

Photograph 14.—Finished pipe “boot”.

Photograph 15.—Completed pipe boot around 4-inch pipe penetration.

Photograph 16.—Membrane at the upstream transition is placed in
a 3-ft cut-off trench to prevent water from getting under the liner.

Photograph 17.—Grader backfills the V-notch anchor trench.

Photograph 18.—Completed test section - exposed LLDPE geomembrane.

SEEPAGE STUDIES

The primary purpose of all the canal-lining alternatives is to conserve water by reducing seepage. Full-scale ponding tests are typically performed both before and after construction to determine the effectiveness of each test section. For 1999, two seepage tests were performed on the RCC-Shotcrete test section (N-5) on the North Unit Canal. The first test consisted of a full-scale postconstruction ponding test, and the second consisted of numerical analysis of Inflow-Outflow data from 1996 through 1999.

Ponding Tests

Ponding tests previously performed over the fractured basalt in the North Unit Canal have shown wide variations in the seepage rate from site to site. Over the past 8 years, ponding tests have shown preconstruction seepage rates from 2.3 to 20.5 ft/day, and postconstruction seepage rates from 0.4 to 3.2 ft/day. These previous ponding tests are shown in Table 3.

Table 3.—Previous Ponding Tests and Estimated Efficiency - North Unit Main Canal

Type of Liner and Estimated Percent Effectiveness	Test* section	Preconstruction 1991 (ft^3/ft^2-day)	Preconstruction 1996 (ft^3/ft^2-day)	Postconstruction 1994 (ft^3/ft^2-day)	Postconstruction 1998 (ft^3/ft^2-day)
RCC Invert Only	Pond 1		20.45		3.18 84% @ 1 yr.
	N!1	3.1!5.4	3.1!5.6		2.53 30% @ 1 yr.
	N!2				
	N!3		2.3!3.8		
	N!4				
40%	N!5				
Shotcrete	N!6			0.44 56% @ 2 yrs.	0.40 60% @ 6yrs.
	N!7				
	N!8				
70%	N!9				

* Vertical spacing represents size and location of test sections and ponding tests.

Most of these ponding tests were performed in areas of suspected high seepage and therefore are not believed representative of the entire canal. However, based on these ponding tests, the following conclusions were listed in the "Year 7 Report."

1 Average unlined seepage rate on North Unit = 1 ft/day

2. Effectiveness of Lining inverts only = 40 percent

3. Effectiveness of concrete lining (RCC or shotcrete) the entire canal = 70 percent

1999 Ponding Test.—In 1999, a full-scale postconstruction ponding test was conducted over a 1,400-ft reach of the North Unit Canal. This 1,400-ft reach is RCC lined in the invert with shotcrete sideslopes. The ponding test was conducted over a 2-day period and shows an average seepage rate of 0.6 ft/day. The ponding data is included in Appendix D, and compared with previous data in table 4 below. Comparing the preconstruction seepage rate of 3 to 4 ft/day with the postconstruction seepage rate of 0.6 ft/day, the RRC/shotcrete lining has an effectiveness of 80 to 85 percent.

Table 4.—Ponding Tests Over RCC Invert with Shotcrete Sideslopes

Type of Liner	Test Section	Preconstruction 1991 (ft^3/ft^2-day)	Preconstruction 1996 (ft^3/ft^2-day)	Preconstruction 1999 (ft^3/ft^2-day)
RCC Invert with Shotcrete Sideslopes	N-1	3.1-5.4	3.1-5.6	0.6
	N-2			
	N-3		2.3-3.8	
	N-4			
	N-5			80-85%

Inflow-Outflow

To better estimate actual preconstruction seepage rates and effectiveness of various linings, inflow-outflow data has been collected for 25 miles of the North Unit Canal for the years 1996, 1998, and 1999. This reach of canal has accurate flow measurement structures at Mile 0 (river diversion), Mile 12½ , and Mile 25. The first 12½ miles are of special interest because 1) there are no farm turnouts, and 2) this section was lined with RCC invert in the fall of 1996, and with shotcrete sideslopes in the fall of 1998. The last 12½ miles remains unlined and also has no turnouts. The inflow-outflow data for these 2 sections are shown in tables 5 and 6.

Table 5.—Inflow-Outflow.—North Unit Main Canal - Mile 0 through Mile 12½

Year	Lining	Total Diverted (acre-ft)	Delivered 12.5 mile (acre-ft)	Loss (acre-ft)	Seepage Rate (ft/day)	Effectiveness (percent)
1996	Unlined	182,274	157,438	24,836	1.52	---
1998	Lined invert only	169,908	152,299	17,609	1.08	30
1999	Fully lined	176,434	170,177	6,257	0.38	75

Table 6.—Inflow-Outflow - North Unit Main Canal - Mile 12½ through Mile 25

Year	Lining	Delivered 12.5 mile (acre-ft)	Delivered 25 mile (acre-ft)	Loss (acre-ft)	Seepage Rate (ft/day)	Effectiveness (percent)
1996	Unlined	157,438	144,679	12,759	0.78	---
1998	Unlined	152,299	140,086	12,213	0.75	---
1999	Unlined	170,177	158,028	12,149	0.74	---

Inflow-Outflow Conclusions:

1. The unlined seepage rate for the North Unit Canal ranges from 0.74 to 1.52 ft/day (averages 1.1 ft/day) which agrees well with our Year 7 estimate of 1 ft/day. The first 12½ miles of canal has a higher unlined seepage rate (1.52 ft/day), with some isolated areas as high as 20 ft/day (1996 ponding test).

2. The effectiveness of RCC lining in the invert only is about 30 percent, which agrees well with the Year-7 estimate of 40 percent effectiveness.

3. The fully-lined seepage rate is 0.38 ft/day, which agrees fairly well with the 1999 ponding test result of 0.6 ft/day.

4. The effectiveness of RCC lining the invert and shotcrete lining the sideslopes is about 75 percent, which agrees well with the Year-7 estimate of 70 percent. This effectiveness also agrees with the 1999 ponding test which shows effectiveness of 80 to 85 percent.

Appendix A-1

Material Data Sheets

Not Included

Test Section O-3

Appendix A-2

Material Data Sheets

Not Included

Test Section O-4

Appendix B

Geology

Not Included

Ochoco Canal

Appendix C

Laboratory Seam Testing

Test Sections O-3 and O-4

USBR Laboratory Testing - Material and Seam Properties

Property	*Test Method*	*Test section O-3 EPDM*	*Test Section O-4 LLDPE*
Thickness, mils	*ASTM D-5199*	*41*	*34*
Parent Material - Tensile *Tensile @ Yield, ppi (psi)* *Tensile @ Break, ppi (psi)* *Elongation @ Break, %*	*ASTM D-882 @ 20 ipm* *EPDM 1-inch strip* *LLDPE dogbone*	 — *54 (1300)* *500*	 *53 (1550)* *156 (4600)* *700*
Factory Seam *Shear, ppi (psi) ** *Peel, ppi (psi)*	*ASTM D-4437 @ 2 ipm*	 *48+ (1200+)* ---	 *59 (1720)* *53 (1550)*
Field Seam - EPDM Tape *Shear, ppi (mode)* *Peel, ppi (mode)*	*ASTM D-4437 @ 2 ipm*	 *16.8 (Adhesive)* *7.5 (Adhesive)*	 *13.3 (Adhesive)* *8.4 (Adhesive)*

* No failure, exceeded extension capacity of machine

Notes :

All reported values are averages calculated from 5 specimens *Values for Parent Material are lower of machine and cross-machine testing effect of inflow-outflow*

Appendix D

1999 Ponding Test Results

Not Included

Test Section N-5

MISSION

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.