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CANAL-LINING DEMONSTRATION PROJECT YEAR 7 DURABILITY REPORT

September 1999

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

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The Deschutes Canal-Lining demonstration Project is a cooperative effort among the Bureau of Reclamation, several irrigation districts, and several geosynthetic lining manufactures. The purpose of this study is to develop low-cost canal-lining technologies to reduce seepage over severe rocky subgrade conditions. The 27 test sections include combinations of geosynthetics, soil, concrete grout, shotcrete, roller compacted concrete, elastomeric coatings, and sprayed-in-place foam. This report assesses the performance of 22 test sections after 1½ to 7 years of service. This report also documents the construction of five addition tests sections .

At this time, 7 of the 27 test sections have failed, while the remaining 20 test sections are in very good to excellent conditions. Each test section covers about 30,000 square feet, and unit construction costs ranged from $1.00 to $4.00 per square foot. Preconstruction and postconstruction ponding test have shown effectiveness at reducing seepage between 70 and 95 percent. The most promising lining alternative demonstate Benefit/Cost ratios between 3.0 and 3.9.

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September 1999

UNITED STATES DEPARTMENT OF THE INTERIOR ' BUREAU OF RECLAMATION

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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.

U.S. Department of the Interior
Mission Statement

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to tribes.

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GLOSSARY

CSPE	=	Chlorosulfonated Polyethylene (Hypalon)
CSPE-R	=	Reinforced Chlorosulfonated Polyethylene
EPDM	=	Ethylene Propylene Diene Monomer
FID	=	Frenchtown Irrigation District
GCL	=	Geosynthetic Clay Liner
HDPE	=	High Density Polyethylene
LAID	=	Lugert-Altus Irrigation District
LLDPE	=	Linear Low Density Polyethylene
OID	=	Ochoco Irrigation District
PE	=	Polyethylene
PET	=	Polyethylene terephthalate
PP	=	Polypropylene
PVC	=	Polyvinyl Chloride
SBS	=	Styrene-Butadiene-Styrene
SPF	=	Spray-applied Polyurethane Foam
UDRBWCP	=	Upper Deschutes River Basin Water Conservation Project
UV	=	Ultraviolet
VLDPE	=	Very Low Density Polyethylene

EXECUTIVE SUMMARY

Reclamation has constructed 27 alternative canal-lining test sections to assess durability and effectiveness (seepage reduction) over severe rocky subgrades. The lining materials include combinations of geosynthetics, shotcrete, roller compacted concrete, grout-filled mattresses, soil, elastomeric coatings, and sprayed-in-place foam. The test sections are predominantly located in central Oregon, with one in Montana and one in Oklahoma. Each test section typically covers 15,000 to 30,000 square feet. The test sections now range in age from 6 months to 7½ years. Preliminary benefit/cost (B/C) ratios have been calculated based on initial construction costs, durability (service life), maintenance costs, and effectiveness (determined by full-scale preconstruction and postconstruction ponding tests). The 27 test sections are divided into 4 canal lining categories as shown in the table 1.

Table 1.—Benefit/Cost Analysis for Canal Linings

Type of Lining	Construction Cost ($/ft2)	Durability (years)	Maintenance Cost ($/ft2-yr)	Effectiveness at Seepage Reduction (percent)	B/C Ratio
Fluid-applied Membrane	$1.40 - $4.33	10 - 20 yrs	$0.010	90 %	0.2 - 1.8
Concrete alone	$1.92 - $2.33	40 - 60 yrs	$0.005	70 %	3.0 - 3.2
Exposed Geomembrane	$1.03 - $1.53	20 - 40 yrs	$0.010	90 %	3.0 - 3.9
Geomembrane with Concrete Cover	$2.43 - $2.54	40 - 60 yrs	$0.005	95 %	3.5 - 3.7

Each of the lining alternatives offer 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 been removed from the study. Most of the problems related to 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 applications such as lining of existing steel flumes.

Concrete - Excellent durability, but only 70 percent long-term effectiveness. Irrigation districts are familiar with concrete and can easily perform required maintenance.

Exposed Geomembrane - Excellent effectiveness (90 percent), but susceptable to mechanical damage from animal traffic, construction equipment and vandalism. Also often difficult to maintain because of irrigation districts unfamiliarity with geomembrane materials, and need for special equipment to perform repairs.

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

Lining of Existing Steel Flumes - Two promising lining alternatives were identified for existing steel flumes:

> Exposed PP - Excellent effectiveness (90 percent). Installed for less than a year, but looks promising. Only drawback is need for extrusion welder to perform maintenance repairs. Other exposed geomembranes (such as HDPE and Hypalon) could also be used for this application.
>
> Liquid Boot - Excellent effectiveness (90 percent). Problems with blistering below the waterline raise questions about durability. Can be repaired with hand-mix version.

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

Maintenance - Through 7 years, maintenance costs have been relatively low for all the lining alternatives. Generally, exposed geomembranes require about twice the maintenance of concrete linings ($0.010 vs. $0.005/ft^2/yr). For all lining alternatives, benefit/cost analysis shows that every $1 spent on maintenance returns $10 to $20 in conserved water by increasing effectiveness and design life. Therefore, a greater emphasis should be placed on maintenance.

New Test Sections - The newest test sections have been in service for less than a year. These test sections include Exposed Polypropylene (PP) over an existing steel flume (test section F-1) Exposed GCL (test section O-1), and Buried GCL (test section O-2). While these test sections look promising, more time is needed to evaluate.

CHAPTER 1
INTRODUCTION

Traditional canal-lining materials typically include compacted earth, reinforced or unreinforced concrete, and (more recently) buried geomembranes. However, for some jobs, these materials are not always viable because either: (1) they are not locally available (such as compacted earth); (2) they are too expensive (such as reinforced concrete); (3) they require easy access for heavy construction equipment (such as slip-forming unreinforced concrete); or (4) they require extensive overexcavation and subgrade preparation (such as buried geomembranes). This study looks at alternative canal-lining materials that are less expensive, easier to construct with limited access, and compatible with severe rocky subgrades such as the fractured volcanic basalt typically found in the Pacific Northwest and other areas.

To date, 27 test sections have been constructed on 7 irrigation districts (5 irrigation districts on the Deschutes River in central Oregon, 1 in Montana, and 1 in Oklahoma). The lining materials include combinations of geosynthetics, shotcrete, grout-filled mattresses, soil, elastomeric coatings, and sprayed-in-place foam. The test sections now range in age from 6 months to 7½ years. Two additional test sections are planned for construction in the fall of 1999 and will be addressed in the *"2000 Supplemental Report."*

This report is the fourth in a series. The first report, "*Deschutes - Construction Report*" (Reclamation Report R-94-06, 1994), documented the construction of the original 18 test sections on the Arnold and North Unit Irrigation Districts near Bend, Oregon (see figures 1 and 2). These 18 test sections were constructed over severe rocky subgrade conditions. The construction report detailed construction techniques, construction materials, unit construction costs, and ponding tests to determine seepage rates both before and after construction of the test sections. Postconstruction seepage rates were 10 to 100 times lower than preconstruction rates. Unit construction costs for the original 18 test sections are included in table 2.

The second report, *"Deschutes - Year 2 Durability Report"* (Reclamation Report R-94-14, 1994), assessed the condition of the original 18 test sections after about 2 years of service (through April 1994).

The third report *"Deschutes - Year 5 Durability Report"* (Reclamation Report R-97-01, 1997), detailed the construction of four additional test sections. Unit construction costs for the four additional test sections are included in table 3. That report also assessed the condition of all 22 test sections after up to 5 years of service (through October 1996).

This fourth report details the construction of five new test sections. Unit construction costs for the new test sections are also included in table 3. This report also assesses the condition of all 27 test sections after up to 7½ years of service (through March 1999). The test sections are evaluated for cost, durability, maintenance requirements, and effectiveness in reducing seepage. These factors are combined to calculate life-cycle costs for use in benefit-cost analysis.

This demonstration project supports the Upper Deschutes River Basin Water Conservation Project (UDRBWCP) study, a cooperative effort among Bureau of Reclamation (Reclamation), the Oregon Water Resources Department, and several local irrigation districts. The UDRBWCP study seeks to improve water use efficiency in the basin to enhance and stabilize Deschutes River flows and to reduce irrigation water shortages. Improved flows will protect and enhance recreation and fish and wildlife.

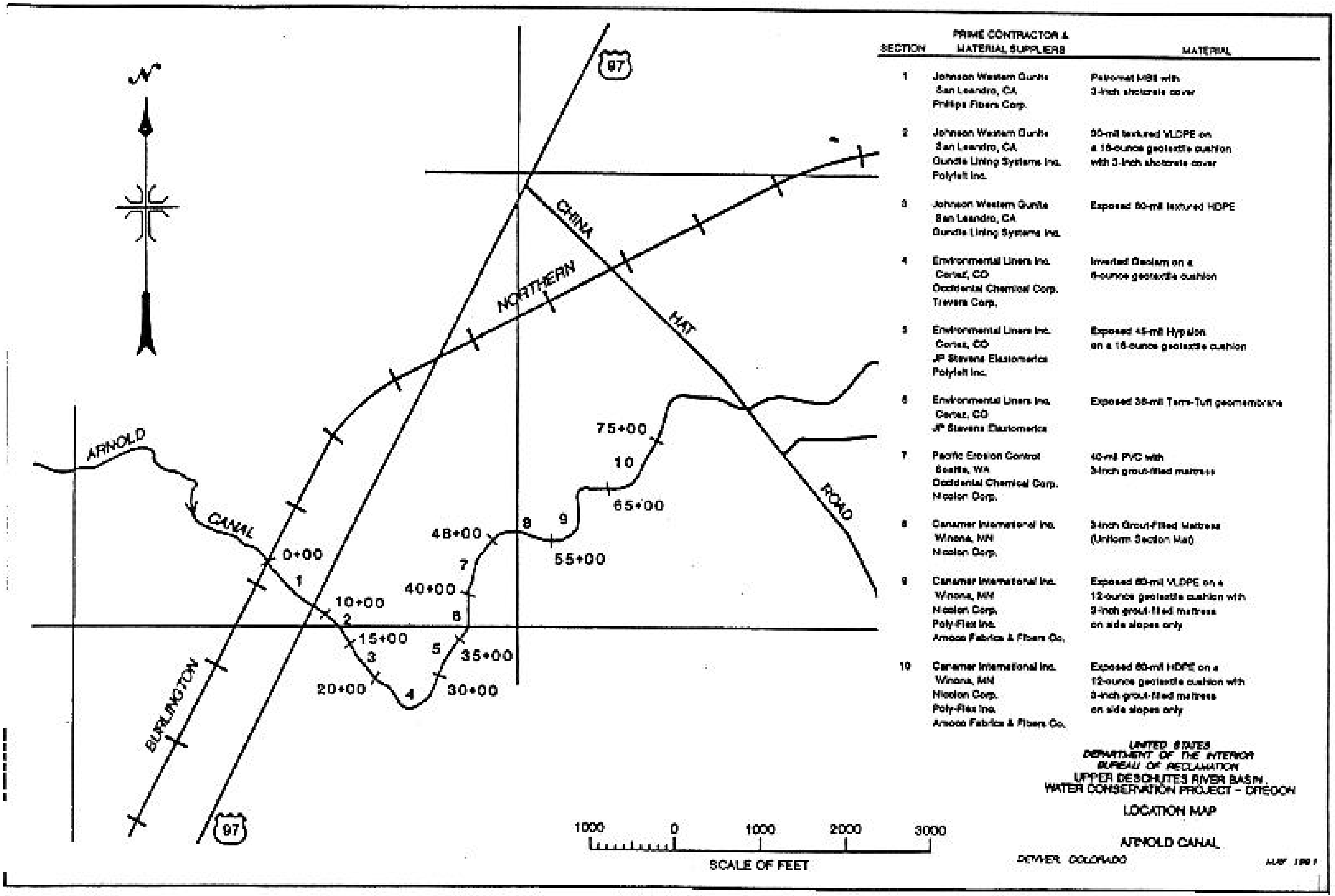


Figure 1 Arnold Canal Location Map

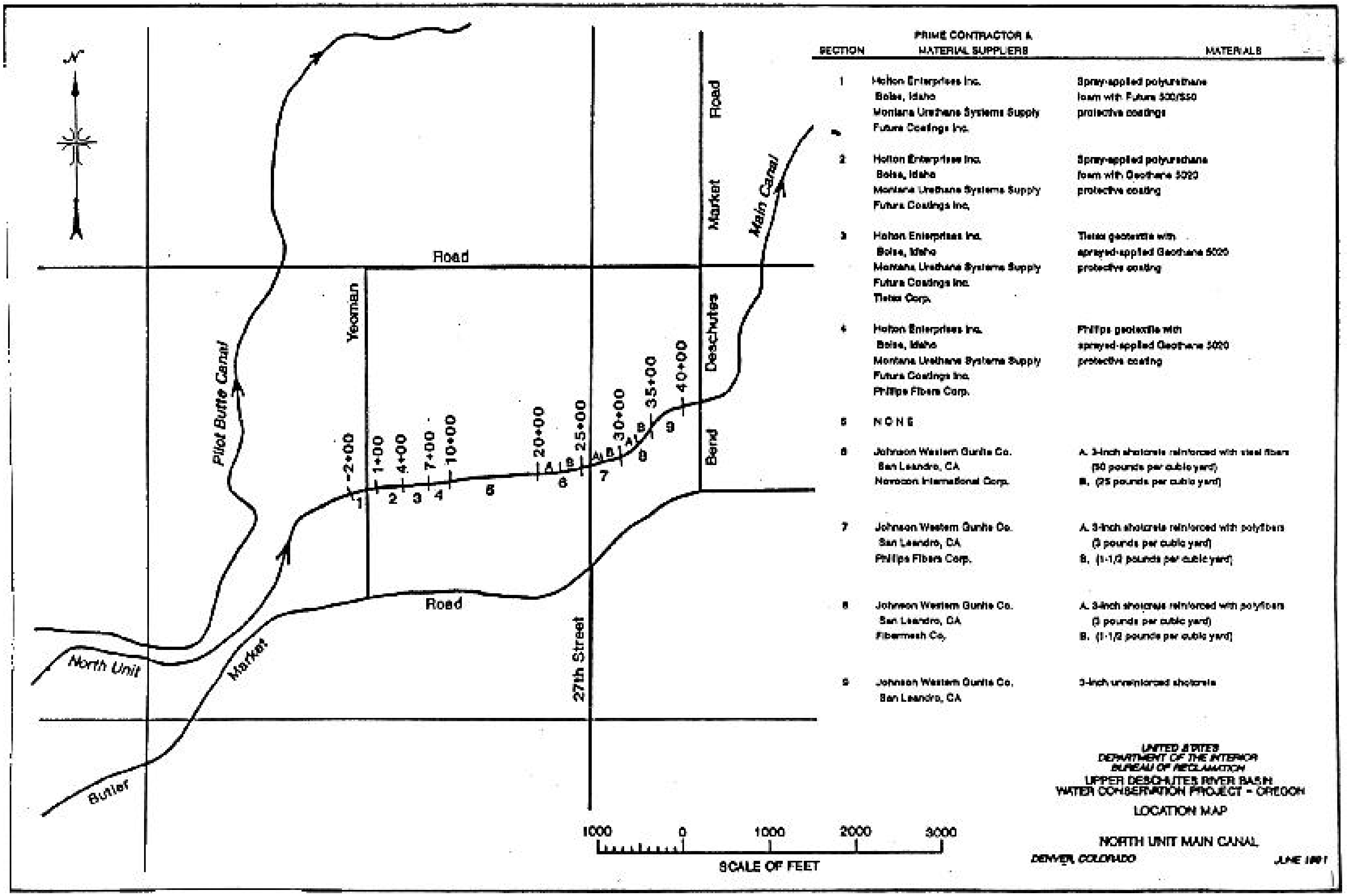


Figure 2 North Unit Main Canal Location Map

Table 2.—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. ft ($)	Installation cost per sq. ft ($)	Overhead and profit (%)	Total ($)
A-1	4-mil PE Geocomposite with Shotcrete cover Unreinforced Shotcrete Polyfiber reinforced Shotcrete	 $0.30 $0.30		 $0.87 $0.87	 $0.06	 $0.26 $0.26	 $0.65 $0.65	 17% 17%	 $2.43 $2.50
A-2	30-mil VLDPE 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 VLDPE or HDPE with 12-oz. geotextile cushion and 3-inch Grout-Gilled Mattress on side slopes 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 side slopes	Contract Bid Price							$2.00
N-6	Shotcrete - Steel-Fiber Reinforced 50 lbs. per cubic yard 25 lbs. per cubic yard			 $1.08 $1.08	 $0.22 $0.11	 $0.04 $0.04	 $0.65 $0.65	 17% 17%	 $2.33 $2.20
N-7 and N-8	Shotcrete Polyfiber Reinforced 3 lbs. per cubic yard 1-1/2 lbs. per cubic yard			 $1.08 $1.08	 $0.12 $0.06	 $0.04 $0.04	 $0.65 $0.65	 17% 17%	 $2.21 $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 3.—Canal lining costs—Tumalo, Lugert-Altus, Juniper Flat, Ochoco, and Frenchtown Test Sections

Section No.	Description	Lining Material				Subgrade Preparation$ / sq. ft	Installation $ / sq. ft	Overhead and Profit %	Total $ / sq. ft
		Geomembrane $ / sq. ft	Geotextile $ / sq. ft	Shotcrete $ / sq. ft	Other Cost $ / sq. ft				
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
F-1	Exposed 45-mil PP over a broomed steel flume	$0.40			$0.12	$0.10	$0.15	17%	$0.90

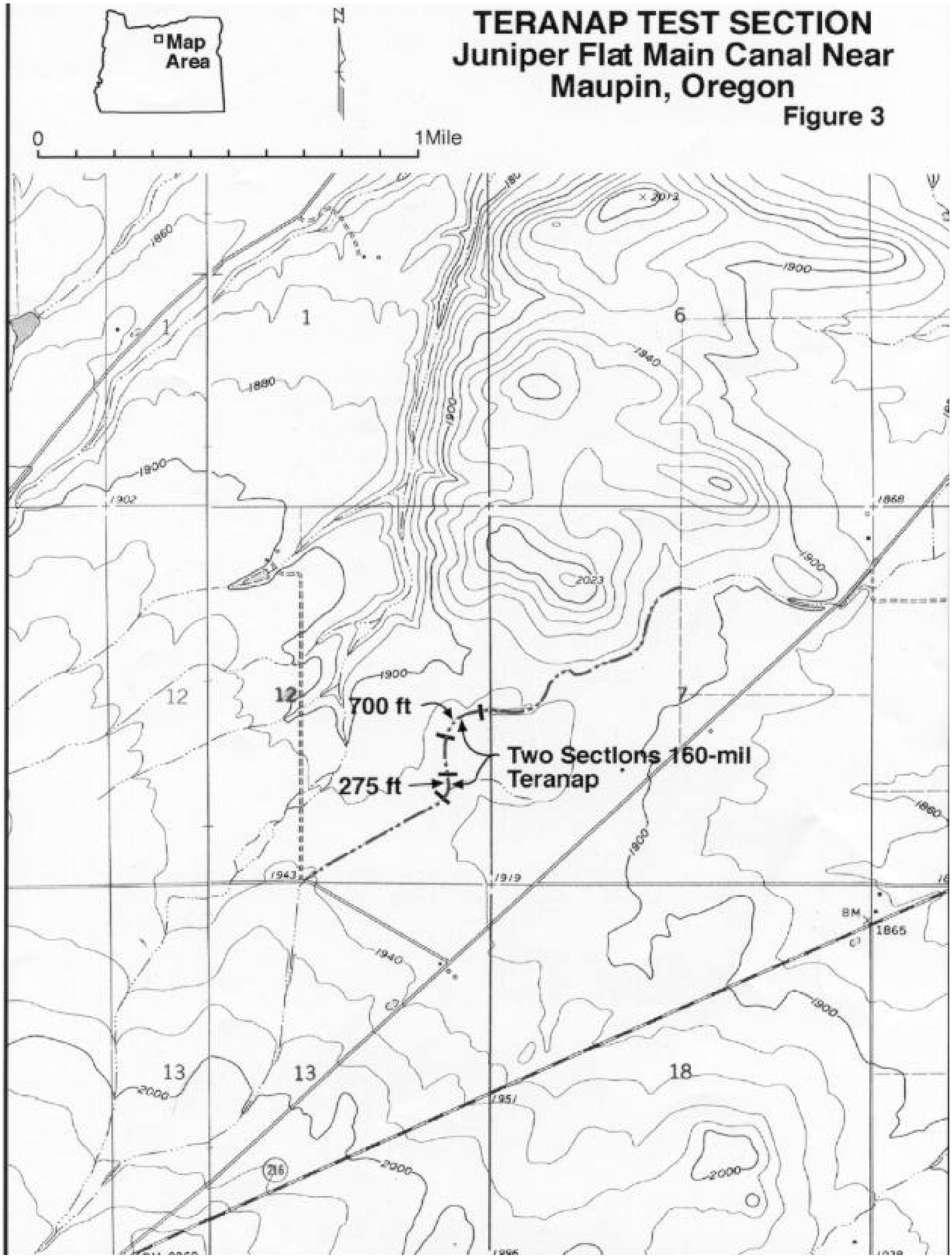
CHAPTER 2
NEW TEST SECTIONS

Juniper Flat District Improvement Company

Background.—The Juniper Flat District Improvement Company is located on Juniper Flat, west of the city of Maupin in central Oregon. Irrigation on Juniper Flat dates back to the early 1900s.
Today, the district provides irrigation water for about 50 district members irrigating about 2,107 acres of land. Main crops are wheat, alfalfa, and pasture. The principal source of water is Clear Creek, which has its beginning in Clear Lake, a natural mountain lake located about 12 miles south of Mount Hood at an elevation of 3500 feet above sea level. The main project features include Clear Lake Dam and 107 miles of canal. The first 30 miles of canal are called the "Mountain Ditch" and carry the water from Clear Lake to the city of Pine Grove. The remaining 77 miles of canal are called the "Main Ditch" and are located on Juniper Flat. These features were constructed or improved by Reclamation in 1959 as part of the Wapinitia Project. The maximum diversion at Clear Creek Dam is 35 cubic feet per second (cfs). The district estimates that 35 to 50 percent of water is lost to seepage over the first 30 miles of the "Mountain Ditch," and another 30 to 35 percent in the Main Ditch.

The test section is located in the "Main Ditch," (see figure 3) about 6 miles downstream of the town of Pine Grove. The maximum flow through the area of the test section is 22.5 cfs at a depth of 2 to 2½ feet. Prior to construction of this small test section, none of the canal was accessible by vehicle, and the entire canal system was monitored by a ditchwalker. Water is delivered on a rotation basis, controlled by the ditchwalker, providing each district member 6 inches of water per rotation.

The area for the test section was selected based on discussions with the district. The test area has long been a problem area for the district, due to washouts and high seepage. Preconstruction ponding tests were performed immediately prior to the test section installation and indicated relatively low seepage rate of 0.26 feet per day (USBR, Burnett, 1997).



TERANAP TEST SECTION
Juniper Flat Main Canal Near
Maupin, Oregon
Figure 3
Map Area
0
1 Mile
700 ft
275 ft
Two Sections 160-mil
Teranap
1
1
6
12
12
7
13
13
18
1860
1880
1900
1902
1940
2012
2023
1943
1919
1868
BM
1865
1951
2000
216

Test Section J-1.—

Material: Exposed 160-mil Teranap

Date Installed: October 1997

Location: Juniper Flat District Improvement Company
(975 linear feet; 26,000 square feet)

Description: Teranap is an elastomeric bitumen geomembrane, combining Styrene-Butadiene-Styrene (SBS) polymer and asphalt with a polyester reinforcement. Teranap is available in 120- and 160-mil thicknesses and roll widths of 2 and 4 meters (6½ and 13 ft). Product data sheets are included in appendix A.

Prime Contractor: Juniper Flat District Improvement Company

Material Supplier: Siplast, Inc.
Evergreen Technologies

Subgrade Prep: Juniper Flat personnel performed extensive subgrade preparation by removing large trees and vegetation that had overgrown the canal. They also removed about 1 foot of mucky sediment. The cost for subgrade preparation is estimated at $0.26 per square foot. This subgrade preparation estimate may be low, but was chosen to match the subgrade preparation estimate used on similar test sections on the Arnold Canal. The finished canal prism measures 25 feet across, plus a 1-ft anchor berm on each bank.

Prior to subgrade preparation, about 3/4 of a mile of dirt road was constructed on both sides of the canal. In addition, rock outcroppings were blasted out of the lower 200 linear feet of the test section. The rock outcroppings were about 2 feet thick and were restricting flow. A total of about 200 sticks of dynamite were used during blasting. After blasting, a small amount of soil bedding was used to fill in any low spots in the irregular blasted rock surfaces. The additional costs for road construction and rock blasting are not included in the $0.26 estimate for subgrade preparation. Finally, any standing water was pumped out of the canal, as seaming of the Teranap liner must be performed in the dry.

Construction: Installation of the Teranap began downstream of the test section (station 12+80) and proceeded upstream to station 5+80 (700 linear feet). The downstream 300 feet used a 16-oz needlepunched nonwoven geotextile cushion over the blasted rock subgrade, while the upstream 400 linear feet had less rock and used no cushion material. The geotextile was provided in rolls measuring 15 by 300 feet. The geotextile was unrolled on the access road, pulled into place in the canal prism, and overlapped in the canal invert.

The Teranap was provided in rolls measuring 4 by 80 meters (13 by 262 feet), and the rolls were installed across the canal. The Teranap rolls were handled by a trackhoe equipped with a bucket attachment provided by Reclamation. The Teranap was first unrolled 4 to 5 feet by hand. The trackhoe then reached across the canal and placed the Teranap roll on the opposite bank. A pickup truck then drove onto the Teranap, securing it in place as the trackhoe arm was retracted, unrolling the Teranap. The Teranap was then cut to match the canal width and pulled into final position by a four-man crew. Adjacent sheets were overlapped 6 to 8 inches, shingled downstream, and seamed with a propane torch by a two-man crew. Finally, the Teranap was secured on the berm by nailing and then backfilled with 6 to 12 inches of cover soil over the notched anchor trench.

Teranap was also installed around the Walters Farm turnout (station 0+00). The Teranap was installed for about 275 linear feet (starting 100 feet upstream of the turnout). The Teranap was again shingled downstream and attached to the concrete turnout with existing stoplog supports that act as batten strips.

Difficulties: The rolls of Teranap are quite heavy (3,500 pounds) and require a large trackhoe, and lots of manpower to install. The irrigation district was short handed for this job. At a minimum, Teranap installation requires four laborers, one trackhoe operator, one truck operator, and one or two 2-man seaming crews. The Teranap can be installed nearly as fast as two seaming crews can seam it, or the seaming can be done later if short handed. Special care should be taken when securing the heavy rolls to lifting bars to protect the laborers working in the canal prism.

Unit Cost Estimate: Exposed 160-mil Teranap with 16-oz geotextile cushion = $1.67 per sq ft
($0.95 Teranap + 0.12 geotextile + 0.26 prep + 0.10 install + 17% OH and profit)

Exposed 160-mil Teranap = $1.53 per square foot
($0.95 Teranap + 0.26 preparation + 0.10 installation + 17% OH and profit)

Advantages: The Teranap is quite tough and resists damage in exposed applications. Installation is fast, simple, and requires no special equipment. Irrigation districts can install this material with their own forces, which allows flexibility in the construction schedule to accommodate bad weather and fluctuating workload. After a little hands-on training in the morning, this inexperienced crew installed 19,000 square feet (6 rolls) of Teranap on the first day. By using their own equipment and labor, the irrigation district was able to install the Teranap at significantly less cost compared to hiring a contractor.

Disadvantages: Exposed geomembranes are susceptible to weathering (especially UV light), animal damage, and vandalism. The Teranap is UV resistant, and quite tough to resist to animal damage. Observed surface cracking is normal for this material.

Photographs: 1 through 23

Juniper Flat District - Test Section J-1
Exposed 160-mil Teranap Geomembrane

Photograph 1.—Preconstruction conditions at Juniper Flats.
Vegetation had overgrown the canal, and large trees lined the canal banks.

Photograph 2.—Trees were removed from the canal bank, and access roads were constructed on both sides of the canal. A Trackhoe reshapes the canal prism by removing the remaining vegetation and 6 to 12 inches of sediment.

Juniper Flat District - Test Section J-1
Exposed 160-mil Teranap Geomembrane

Photograph 3.—Finished canal prism is ready for Teranap installation.

Photograph 4.—Station 12+00 - Trackhoe unsuccessfully attempts to remove rock outcroppings that are restricting flow in the canal invert.

Juniper Flat District - Test Section J-1
Exposed 160-mil Teranap Geomembrane

Photograph 5.—Crew drills holes for blasting rock in the canal invert.

Photograph 6.—Half sticks and full sticks of dynamite were used for blasting the rock outcroppings.

Juniper Flat District - Test Section J-1
Exposed 160-mil Teranap Geomembrane

Photograph 7.—Fire in the hole!

Photograph 8.—Fractured rock in canal invert after blasting.

Juniper Flat District - Test Section J-1
Exposed 160-mil Teranap Geomembrane

Photograph 9.—Following blasting, loose rock was removed, and low spots were filled with a small amount of soil for bedding.

Photograph 10.—Prior to lining installation, all standing water was pumped out of the canal invert. Note V-notch used for anchor trench.

Juniper Flat District - Test Section J-1
Exposed 160-mil Teranap Geomembrane

Photograph 11.—For the lower 300 feet of canal lining (station 9+80 to 12+80), geotextile was rolled out in the road and then pulled into the canal prism as a cushion beneath the geomembrane liner.

Photograph 12.—Installation. First, the Teranap was unrolled about 5 feet by hand; then, the trackhoe sets the liner roll on the far canal bank.

Juniper Flat District - Test Section J-1
Exposed 160-mil Teranap Geomembrane

Photograph 13.—Truck anchors the Teranap, while the trackhoe unrolls the liner across the canal.

Photograph 14.—Crew cuts the Teranap to match the width of the canal.

Juniper Flat District - Test Section J-1
Exposed 160-mil Teranap Geomembrane

Photograph 15.—Four-man crew positions the Teranap and then anchors it to the berm with large nails.

Photograph 16.—Two-man crew seams adjacent panels of Teranap liner.

Juniper Flat District - Test Section J-1
Exposed 160-mil Teranap Geomembrane

Photograph 17.—Trackhoe backfills cutoff trenches at upstream and downstream ends of Teranap installation.

Photograph 18.—Finished Teranap installation, including backfilling over the V-notch anchor trench.

Juniper Flat District - Test Section J-1
Exposed 160-mil Teranap Geomembrane

Photograph 19.—The Walters Turnout at station 0+00 was overgrown with vegetation.

Photograph 20.—Canal has been dewatered, and the trees have been removed from the canal banks. Cracks in the canal invert show the poor condition of the concrete turnout structure.

Juniper Flat District - Test Section J-1
Exposed 160-mil Teranap Geomembrane

Photograph 21.—Teranap has been installed in the downstream portion of the Walters Turnout.

Photograph 22.—Teranap is bolted to the concrete turnout structure with existing stoplog supports used as batten strips.

Juniper Flat District - Test Section J-1
Exposed 160-mil Teranap Geomembrane

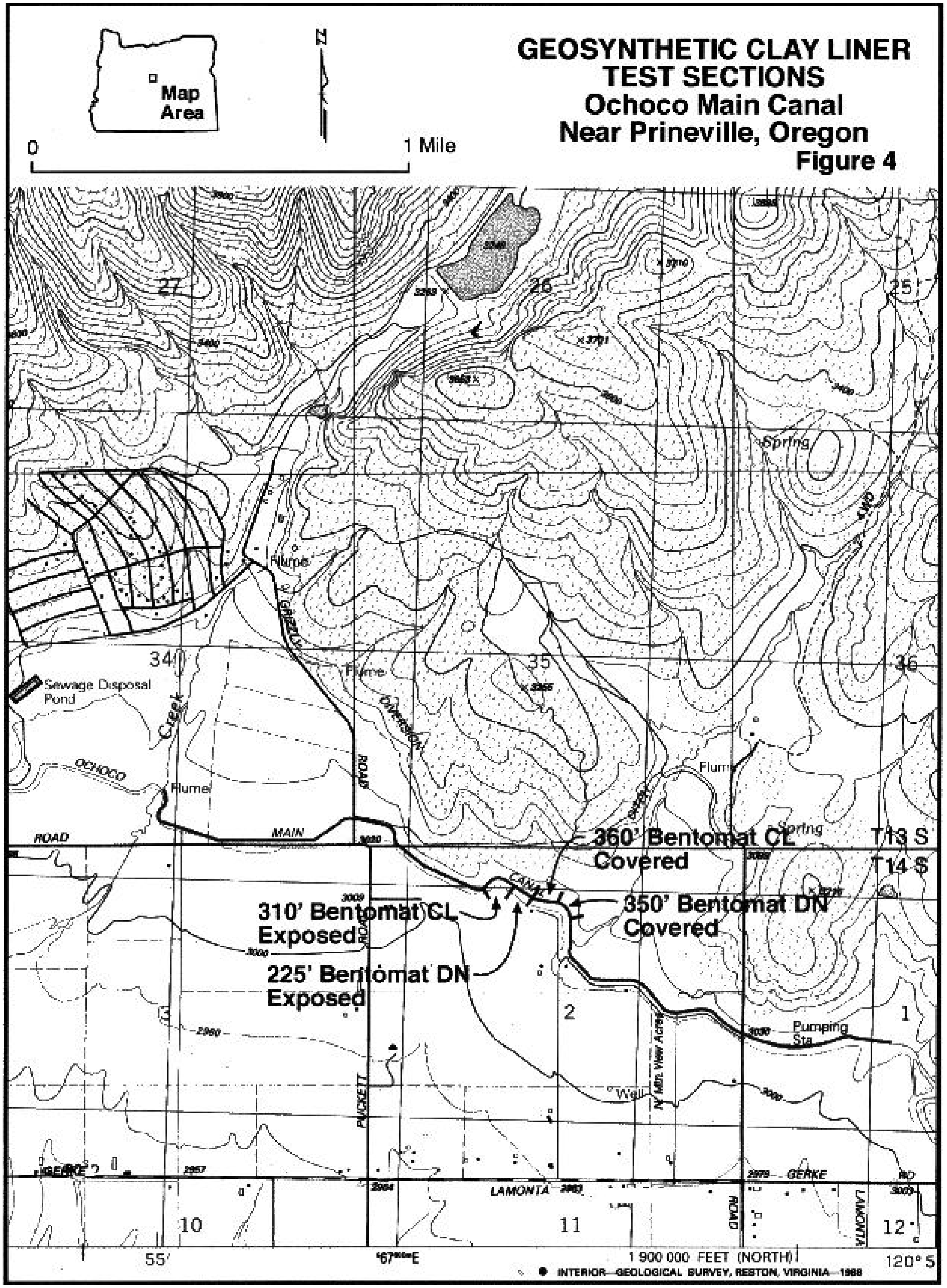
Photograph 23.—Closeup of the bolted attachment of the Teranap to the turnout.

Ochoco Irrigation District

Background.—The Ochoco Irrigation District (OID) was organized in 1916 and is located around 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; whereas 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 per 1,000 feet of length (0.1%).

The test section is located on the Main Canal (see figure 4), about 6 miles northwest of the city of Prineville. The maximum flow through the test section 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 area has long been a problem with high seepage. Water from the canal seeps into the basement of a house situated next to the canal. Ponding tests in the immediate area of the test section will be performed in the near future to determine preconstruction and postconstruction seepage rates, for reporting in the “2000 Supplemental Report.”



Test Sections O-1 and O-2 .—

Material: O-1a = Covered GCL - Bentomat DN

O-1b = Covered GCL - Bentomat CL
O-2a = Exposed GCL - Bentomat DN
O-2b = Exposed GCL - Bentomat CL

Date installed: April 1999

Location: Ochoco Irrigation District
(1,245 linear feet; 50,000 square feet)

Description: CETCO Bentomat DN is a reinforced GCL consisting of a layer of sodium bentonite encapsulated between two needle-punched nonwoven geotextiles. Rolls measure 14 feet wide by 150 feet long. Product data sheet is included in appendix A.

CETCO Bentomat CL is a reinforced GCL consisting of a layer of sodium bentonite encapsulated between a woven and a needle-punched nonwoven geotextile laminated to a thin geomembrane. Rolls measure 14½ feet wide by 150 feet long. Product data sheet is included in appendix A.

Prime Contractor: Ochoco Irrigation District

Material Supplier: CETCO - Colloid Environmental Technologies Company

Subgrade Prep: Ochoco personnel performed extensive subgrade preparation by removing vegetation from the canal and restoring the 1½:1 side slopes (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 previous Arnold test sections. The finished canal prism measures 35 to 45 feet across, plus a 1 to 2 foot anchor trench on each bank.

Construction: Installation of the GCL centered around a house adjacent to the canal, as water (probably from the canal) was occasionally flooding the basement. Starting about 700 feet upstream from the house, the first 350 feet used the Bentomat DN GCL with about 6 inches of soil cover. The next 360 feet used the Bentomat CL GCL with about 6 inches of soil cover. The next 225 feet used exposed Bentomat DN GCL, and the final 310 feet used exposed Bentomat CL GCL. Panels of GCL were shingled in the downstream direction (upstream over downstream), and the Bentomat CL was installed with the geomembrane side down.

Both types of GCL were provided in rolls measuring about 14 feet by 150 feet, and the rolls were installed across the canal. The GCL rolls were handled by a trackhoe equipped with a bucket attachment fabricated by the district (drawings provided by the GCL manufacturer). The trackhoe first placed the GCL roll in the canal invert, where a clamping device was secured to the roll end. Then the trackhoe (assisted by a dozer on the opposite bank) unrolled the GCL and pulled the panel into place. The GCL was then cut to match the canal width, and any final positioning was accomplished by a six-man crew. Adjacent sheets were overlapped 6-12 inches, shingled downstream, and seamed with granular Bentonite sprinkled into the seam. Finally, the GCL was secured by backfilling the anchor trench. The exposed GCL was further secured with four 12-inch spikes per panel. The spikes were #3 rebar or 3/8-inch diameter nails with 2-inch washers.

Difficulties: The forklift operator tore several rolls of GCL picking them off the ground. The tears often damaged 2-3 layers per roll. Damaged GCL was either discarded or patched by covering with additional GCL. Patches covered the damaged area for at least 1 foot in all directions, and granular Bentonite was sprinkled into the seams.

The rolls of GCL are quite heavy (3,000 pounds), and required a large trackhoe, a dozer, a backhoe, a large forklift, a grader, and lots of manpower to install (note that large rolls of Teranap require similar amounts of equipment). An extra lifting bar would eliminate a bottleneck and speed up the installation. To protect the laborers working in the canal prism, special care should be taken when securing the heavy rolls of GCL to lifting bars.

Unit Cost Estimate: Covered GCL Bentomat DN = $0.82 per square foot
($0.29 GCL + 0.26 prep + 0.10 install + 0.05 burial + 17% OH and profit)

Covered GCL Bentomat CL = $0.87 per square foot
($0.33 GCL + 0.26 prep + 0.10 install + 0.05 burial + 17% OH and profit)

Exposed Bentomat DN GCL = $0.76 per square foot
($0.29 GCL + 0.26 prep + 0.10 install + 17% OH and profit)

Exposed Bentomat CL GCL = $0.81 per square foot
($0.33 GCL + 0.26 prep + 0.10 install + 17% OH and profit)

Advantages: Installation is fast, simple, and requires no special equipment. Irrigation districts can install this material with their own equipment and personnel, 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 50,000 square feet (30 rolls) in two 10-hour days. By using their own equipment and labor, the district was able to install the GCL at significantly less cost compared to hiring a contractor.

Disadvantages: GCLs are typically covered with a minimum of 12 inches of cover material. Use in a canal with flowing water and only 6 inches of cover is a new application. Exposed GCLs will be subject to environmental as well mechanical damage.

Photographs: 24 through 41

Ochoco Irrigation District - Test Sections O-1 and O-2
Covered GCL and Exposed GCL

Photograph 24.—Unlined canal prior to construction of GCL test sections.

Photograph 25.—Subgrade preparation consisted of removing vegetation and providing smooth subgrade. Note the V-notch anchor trench.

Ochoco Irrigation District - Test Sections O-1 and O-2
Covered GCL and Exposed GCL

Photograph 26.—Transition between covered Bentomat CL and exposed Bentomat DN.

Photograph 27.—Packing label identifying Bentomat DN, lot number, roll number, etc.

Ochoco Irrigation District - Test Sections O-1 and O-2
Covered GCL and Exposed GCL

Photograph 28.—Trackhoe and lifting bar for handling heavy rolls of GCL.

Photograph 29.—Lifting bar with yoke attached to GCL roll.
Material was placed during cold weather (35 EF) with periods of light snow.

Ochoco Irrigation District - Test Sections O-1 and O-2
Covered GCL and Exposed GCL

Photograph 30.—Overall placing operation. Trackhoe maneuvered GCL roll, while tractor pulled sheet across the canal. Final adjustments were made by a four- to six-man crew.

Photograph 31.—Seaming with granular Bentonite before placement of next overlapping GCL panel. Granular bentonite applied at about ¼ pound per linear foot.

Ochoco Irrigation District - Test Sections O-1 and O-2
Covered GCL and Exposed GCL

Photograph 32.—In the exposed application, four pins were used to secure each seam. No. 3 rebar was originally used, but it was too weak.

Photograph 33.—Three-eighths-inch spikes with 2-inch washers used to secure seams and patches in the exposed GCL test sections.

Ochoco Irrigation District - Test Sections O-1 and O-2
Covered GCL and Exposed GCL

Photograph 34.—Damaged GCL repaired with granular Bentonite and GCL patch.

Photograph 35.—Backhoe has placed soil cover over half the GCL (Bentomat CL) in the canal prism. Native soil was placed in the bottom of canal and worked up to the top of the bank.

Ochoco Irrigation District - Test Sections O-1 and O-2
Covered GCL and Exposed GCL

Photograph 36.—Grader backfilling the anchor trench.
Completed section of exposed Bentomat DN.

Photograph 37.—Completed section of exposed Bentomat CL.

Ochoco Irrigation District - Test Sections O-1 and O-2
Covered GCL and Exposed GCL

Photograph 38.—Finished test section with buried GCL.

Photograph 39.—Completed test section with exposed GCL Bentomat DN.

Ochoco Irrigation District - Test Sections O-1 and O-2
Covered GCL and Exposed GCL

Photograph 40.—Exposed seam edges are curling after 2 months' service. Curling edges are more prevalent in the exposed Bentomat CL than in the Bentomat DN.

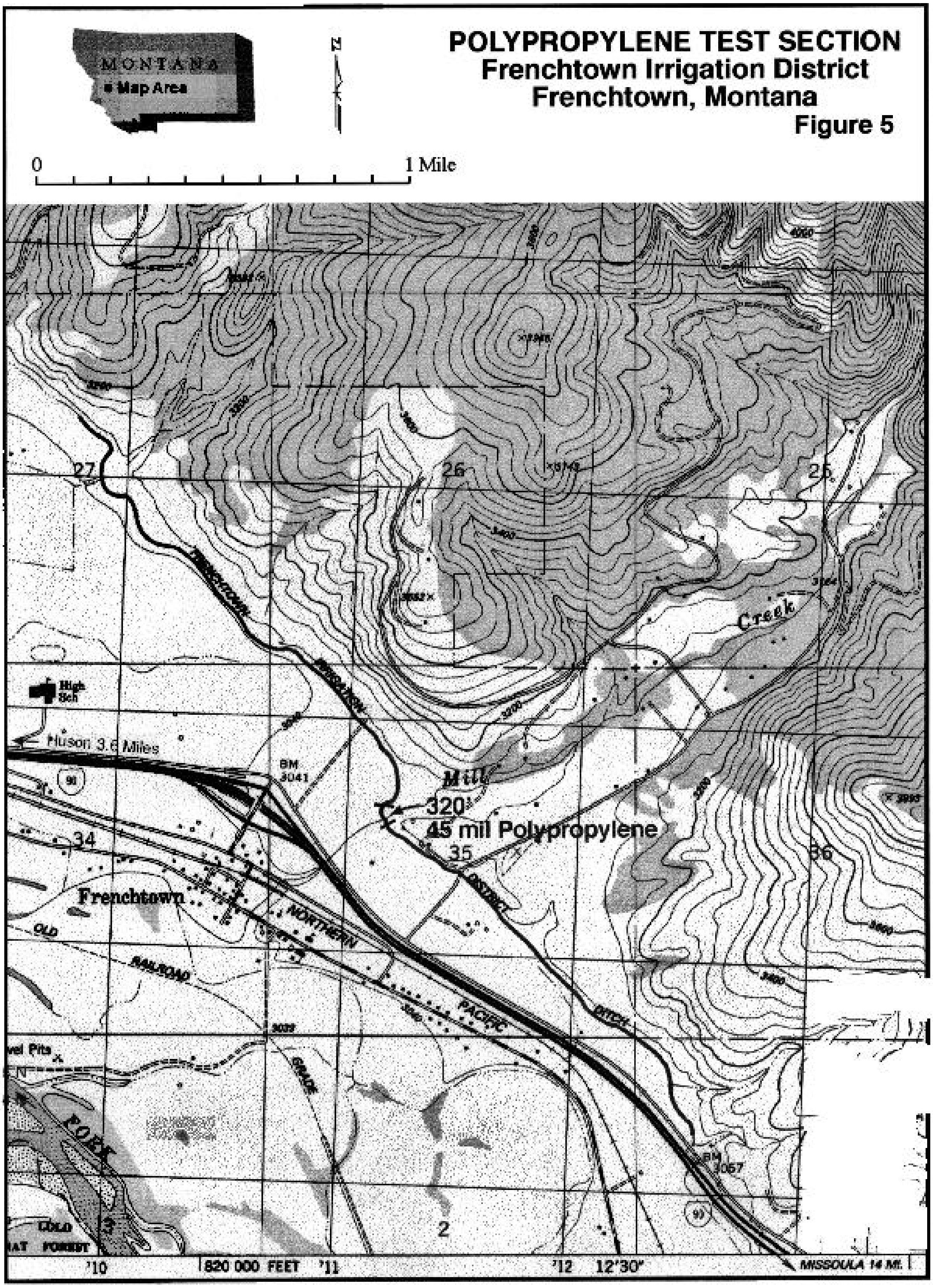
Photograph 41.—Closeup of curled seam edges in exposed CL test section.

Frenchtown Irrigation District

Background.—The Frenchtown Irrigation District (FID) was organized in 1936 and is located around the city of Frenchtown, Montana, about 12 miles northwest of Missoula.

The district provides irrigation water for 48 water users irrigating 4,575 acres. The principal source of water is the Clark Fork River. Frenchtown Irrigation District was constructed in 1936 and 1937. The first water was delivered on May 18, 1937. Additional project features include 17 miles of main canal and 21 miles of open laterals. Almost all of the canals and laterals are unlined. Typically, canals flow on a grade of 1 foot per 1,000 feet of length (0.1%).

The test section is a steel flume over Mill Creek, located on the Main Canal about 1 mile northeast of the city of Frenchtown, see figure 5. The maximum flow through the test section is 80 to 100 cfs at a depth of about 3 feet. The site for the test section was selected based on discussions with the district. The test area has long been a problem due to high leakage. Ponding tests in the immediate area of the test section have not been performed. However, visual estimates will be possible, as leakage can be seen from the outside of the flume.



POLYPROPYLENE TEST SECTION
Frenchtown Irrigation District
Frenchtown, Montana
Figure 5

Test Section F-1.—

Material: Exposed 45-mil reinforced polypropylene (PP) over an existing steel flume

Date installed: April 1999

Location: Frenchtown Irrigation District - Mill Creek Flume
(320 linear feet; 3,640 square feet)

Description: Steel flume consists of a wooden frame with 3-ft sections of sheet metal. The flume is 320 feet long with a 12-ft perimeter. The liner is 45-mil reinforced polypropylene formulated for exposed applications. The reinforcement is a 10 by 10 fibers per inch polyester scrim.

Prime Contractor: Frenchtown Irrigation District (Installer)
Environmental Liners (Fabricator)

Material Supplier: JPS Elastomerics

Subgrade prep: District performed minor subgrade preparation by sweeping out the flume and removing vegetation growing over the flume. Drain holes (½-inch diameter) were drilled in the flume invert on 50-ft centers. Drain holes were covered with a 12-oz needle-punched nonwoven geotextile prior to installation of the liner. The top edges of the sheet metal were covered with foam pipe insulation prior to liner installation.

Construction: The polypropylene liner was fabricated into a single panel measuring 14 feet by 360 feet, and accordion-folded in two directions. The panel was unfolded inside the flume by a six-man crew. Starting at the flume midpoint, the panel was pulled up the sides and secured into place with 1-inch by 4-inch battens nailed into the 4-inch by 6-inch stringers. At the upstream transition, the liner was secured to the concrete with 1/8-inch by 1½-inch stainless steel batten. The batten was secured with drilled concrete anchors on 6-inch centers. At the downstream transition, the liner was buried in a 1-foot-deep anchor trench.

Difficulties: The PP geomembrane was ordered in a 14-ft-wide panel. However, the delivered panel measured 18 feet wide, making it more difficult to pull into the flume and handle. After initial positioning, 4 feet was trimmed from one side of the panel.

The PP geomembrane was attached to the upstream concrete transition with a stainless steel batten, and attempts were made to attach the battens trip with concrete nails from a Hilte gun. However, the Hilte gun could not set the nails into the old concrete. Instead, it was necessary to attach them with drilled concrete anchors on 6-inch centers.

Unit Cost Estimate: Exposed Reinforced PP over an existing steel flume = $0.90 per square foot ($0.40 material + $0.12 fabrication + $0.10 preparation + $0.15 installation + 17% OH and profit)

Advantages: Exposed PP should have a durability of 20 to 40 years and should offer excellent seepage reduction. Exposed geomembranes are relatively easy to install. On this job, the district and Reclamation personnel installed the liner without assistance from a contractor or from the PP manufacturer.

Disadvantages: Exposed geomembranes are subject to mechanical damage (animal traffic, equipment damage, and vandalism) as well as weathering.

Photographs: 42 through 65

Frenchtown Irrigation District - Test Section F-1
Exposed 45-mil Reinforced Polypropylene

Photograph 42.—Preconstruction conditions at Mill Creek Flume.
Vegetation had overgrown flume along both sides.

Photograph 43.—Swamp had developed from seepage through joints in 3-foot steel panels.

Frenchtown Irrigation District - Test Section F-1
Exposed 45-mil Reinforced Polypropylene

Photograph 44.—Vegetation was removed for easy access and installation.

Photograph 45.—To protect the lining, preslit pipe insulation
was used over the flume's exposed steel edges.

Frenchtown Irrigation District - Test Section F-1
Exposed 45-mil Reinforced Polypropylene

Photograph 46.—Cleaned flume with pipe insulation installed along both sides.

Photograph 47.—Lining was delivered on a pallet which was lowered into the canal.

Frenchtown Irrigation District - Test Section F-1
Exposed 45-mil Reinforced Polypropylene

Photograph 48.—Tow rope was tied to the liner around a softball-size rock.

Photograph 49.—A small winch pulls the lining through the flume.

Frenchtown Irrigation District - Test Section F-1
Exposed 45-mil Reinforced Polypropylene

Photograph 50.—Lining was pulled through the flume in a single piece, eliminating the need for field seams.

Photograph 51.—Four feet was trimmed from one side of the lining (the panel was ordered 14 feet wide, but was delivered 18 feet wide).

Frenchtown Irrigation District - Test Section F-1
Exposed 45-mil Reinforced Polypropylene

Photograph 52.—Four-man crew unfolds the liner inside the flume.

Photograph 53.—Extra layer of PP liner used as cushion over sharp offset joints in the steel flume.

Frenchtown Irrigation District - Test Section F-1
Exposed 45-mil Reinforced Polypropylene

Photograph 54.—Vise grips hold the liner in position ahead of the nailing operation.

Photograph 55.—The lining was wrapped around the 1 x 4 batten and nailed (with an air-powered nailer) to the 4 x 6 stringer on the outside of the flume.

Frenchtown Irrigation District - Test Section F-1
Exposed 45-mil Reinforced Polypropylene

Photograph 56.—Wrinkles indicate that the liner was installed in a slack condition.

Photograph 57.—Downstream transition ready for burial in anchor trench.

Frenchtown Irrigation District - Test Section F-1
Exposed 45-mil Reinforced Polypropylene

Photograph 58.—Crew attempts to use Hilte gun to attach liner to the concrete upstream transition. Hilte gun could not set the nails into the old concrete.

Photograph 59.—Stainless steel batten attached with drilled concrete anchors. Calking was also used for additional seepage protection.

Frenchtown Irrigation District - Test Section F-1
Exposed 45-mil Reinforced Polypropylene

Photograph 60.—Finished lining at first water run.

Photograph 61.—No leakage in previous swamp area.

Frenchtown Irrigation District - Test Section F-1
Exposed 45-mil Reinforced Polypropylene

Photograph 62.—Small wrinkles during water run indicate that the liner was installed correctly at this location, with small amount of excess slack.

Photograph 63.—Absence of wrinkles indicate that the liner is a little tight at this location.

Frenchtown Irrigation District - Test Section F-1
Exposed 45-mil Reinforced Polypropylene

Photograph 64.—Closeup of the liner stretched tight, compressing the pipe insulation over edge of flume.

Photograph 65.—Finished installation at downstream concrete transition.

Test Section N-5.—

Material: Roller-Compacted Concrete (RCC) Invert with Shotcrete Side Slopes

Date Installed: Spring 1998 - RCC Invert (2.2 million square feet)
Spring 1999 - Shotcrete Side Slopes (1.4 million square feet)

Location: North Unit Irrigation District (see figure 1 for location of N-5)
(12 linear miles; 3.6 million square feet)

Description: Canal invert has 6 inches average of RCC; side slopes have 3 inches minimum (4 inches average) of polyfiber reinforced shotcrete. The polyfiber reinforcement is Fibermesh at 1½ pounds per cubic yard.

Contractor: HDR Engineering (Consultants)
Barnard Construction (RCC invert)
JAL (Shotcrete side slopes)

Subgrade Prep: RCC Invert - Contractor constructed access roads into the canal invert as needed. Contractor placed about 3 to 12 inches of cohesionless fill (cinders) in the invert to fill low spots and provide a smooth surface for the RCC.

Shotcrete Side Slopes - Contractor began by applying the shotcrete directly over the rocky side slopes. Because of the large amount of shotcrete required (6 inches average) to achieve the required 3-inch minimum thickness, the contractor found it more economical to remove, crush, and recompact about 2 feet of side slope material on a 1½ slope. With the smoother subgrade surface, the average shotcrete thickness decreased to about 4 inches.

Construction: RCC was installed in the invert to an average thickness of 6 inches.

Shotcrete was applied to the side slopes at an average thickness of 4 inches (3 inches minimum). In some areas, ½-inch steel mesh was attached over large rock outcroppings, and the 3-inch shotcrete was applied over the mesh.

Difficulties: Rocky conditions provided irregular subgrade. Contractor used cinders as fill for the RCC invert, and removed, crushed, and recompacted side slope material to achieve a smooth subgrade surface.

Large amounts of cinders were used to build up the natural drops, creating ramps for smooth application of the RCC. When water was first turned on, extremely high velocities damaged RCC in the ramp areas. Therefore, the district removed the RCC ramps and replaced with large riprap for energy dissipation in fall 1998.

Unit Cost: RCC Invert = $1.74 per square foot (based on actual bid price)
Shotcrete Side Slopes = $2.49 per square foot (based on actual bid prices)
Combined = $2.00 per square foot (40-ft invert with 10-ft side slopes)

Advantages: RCC and shotcrete provide a hard surface that is not susceptible to vandalism or animal damage and allows the operation of maintenance equipment in the canal prism.

Disadvantages: Seepage is expected to increase over the years as RCC and shotcrete age and crack.

Photographs: 66 through 78

North Unit Main Canal - Test Section N-5
Roller-Compacted Concrete Invert with Shotcrete Side Slopes

Photograph 66.—Contractor placed cinders in the canal invert to provide a smooth, firm subgrade (photograph courtesy of HDR Engineering).

Photograph 67.—Roller-compacted concrete was placed over the cinders (photograph courtesy of HDR Engineering).

North Unit Main Canal - Test Section N-5
Roller-Compacted Concrete Invert with Shotcrete Side Slopes

Photograph 68.—Trackhoe removes about 2 feet of side slope material.

Photograph 69.—Rock crusher reduces large rocks to about 1 inch maximum.

North Unit Main Canal - Test Section N-5
Roller-Compacted Concrete Invert with Shotcrete Side Slopes

Photograph 70.—Another trackhoe places the crushed rock on the 1½:1 side slopes.

Photograph 71.—A third trackhoe with hydraulically controlled foot compacts the side slopes.

North Unit Main Canal - Test Section N-5
Roller-Compacted Concrete Invert with Shotcrete Side Slopes

Photograph 72.—Rocks too large to crush are covered with mesh prior to shotcrete application.

Photograph 73.—Bobcat with cutting wheel cuts anchor trench in the RCC invert.

North Unit Main Canal - Test Section N-5
Roller-Compacted Concrete Invert with Shotcrete Side Slopes

Photograph 74.—Anchor trench in the RCC invert is about 3 inches wide by 6 inches deep.

Photograph 75.—Equipment (and subcontractor) for shotcrete application are the same as in previous test sections N-6 through N-9.

North Unit Main Canal - Test Section N-5
Roller-Compacted Concrete Invert with Shotcrete Side Slopes

Photograph 76.—New shotcrete applied over old shotcrete, estimated to be about 45 years old.

Photograph 77.—Completed test section N-5 - looking west.

North Unit Main Canal - Test Section N-5
Roller-Compacted Concrete Invert with Shotcrete Side Slopes

Photograph 78.—First water run on completed test section
with RCC invert and shotcrete side slopes (N-5).
(Photograph taken looking upstream from station 35+00).

CHAPTER 3
CONDITION ASSESSMENT

Visual Inspections

All 27 test sections have been visually inspected annually to monitor lining condition, assess durability, and evaluate maintenance requirements. The most recent inspections were performed in March 1999 when the Arnold test sections were 6½ to 7½ years old, the North Unit test sections were 6½ to 7 years old, the Tumalo test sections were 4 to 5 years old, the Lugert-Altus test section was 5 years old, and the Juniper Flat test section was 1½ years old. The condition of each test section is summarized in table 4, 5, and 6.

Table 4.—7-Year Condition Assessment - Arnold Test Sections

No.	Test section	2-year condition	4-year condition	7-year condition	Comments
A-1	4-mil PE geocomposite with shotcrete cover	Excellent	Excellent	Excellent	No Problems
A-2	30-mil VLDPE with Shotcrete cover	Excellent	Excellent	Excellent	No Problems
A-3	Exposed 80-mil HDPE	Very Good to Excellent	Very Good	Very Good	Several small tears and cuts
A-4	Exposed 30-mil PVC geomembrane with geotextile UV cover	Excellent	Very Good	Good	Several small tears and cuts
A-5	Exposed 45-mil Hypalon with 16-oz geotextile cushion	Excellent	Very Good	Very Good	Several small tears and cuts
A-6	Exposed 36-mil Hypalon with 8-oz geotextile cushion	Very Good to Excellent	Very Good	Very Good	Several small tears and cuts
A-7	40-mil PVC with 3-inch Grout-filled Mattress	Excellent	Excellent	Excellent	Needs Minor Repairs
A-8	3-inch Grout-filled Mattress	Excellent	Excellent	Excellent	Needs Minor Repairs
A-9 and A-10	Exposed VLDPE or HDPE with grout-filled mattress on side slopes only	Marginal	Removed from Study after 28 months		Liner "whales" were impeding flow

Table 5.—7-Year Condition Assessment - North Unit Test Sections

No.	Test section	2-year condition	4-year condition	7-year condition	Comments
N-1	SPF with Futura 500/550 Protective Coating	Partially Failed 25%	Partially Failed 50%	Removed	Replaced with RCC
N-2	SPF with Futura 500/550 Protective Coating	Partially Failed 10%	Partially Failed 30%	Removed	Replaced with RCC
N-3	Tietex Geotextile with Geothane 5020 Protective Coating	Failed May 93	---	Removed	Replaced with RCC
N-4	Phillips Geotextile with Geothane 5020 Protective Coating	Failed May 93	---	Removed	Replaced with RCC
N-5	RCC invert with Shotcrete side slopes	---	---	---	New - installed April 1999
N-6	Shotcrete with steel fibers	Excellent	Excellent	Excellent	No Problems
N-7	Shotcrete with polyfibers	Excellent	Excellent	Excellent	No Problems
N-8	Shotcrete with polyfibers	Excellent	Excellent	Excellent	No Problems
N-9	Unreinforced Shotcrete	Excellent	Excellent	Excellent	No Problems

Table 6.—Condition Assessment - Tumalo, Lugert Altus, and Juniper Flat Test Sections

No.	Test section	2-year condition	5-year condition	Comments
T-1	Liquid Boot over an Existing Concrete Flume	Poor	Removed	Replaced with Buried Pipe
T-2	Liquid Boot over a Sandblasted Steel Flume	Very Good	Good	50+ blisters
T-3	Liquid Boot over a Broomed Steel Flume	Very Good	Good	50+ blisters
L-1	Exposed 160-mil Teranap Geomembrane	Very Good	Very Good	Partial Washout Repaired 1996 No further problems
J-1	Exposed 160-mil Teranap Geomembrane	Very Good	---	No problems

Ice Jams.—Many canals, including the Arnold Canal, do not have adequate slope to drain when the water is turned off. Ponds form in these locations (typically 6 to 12 inches deep), and rain and snow add to the ponds. Before lining the Arnold test sections, these ponds were not a problem, because the water would slowly seep out of the unlined canal. However, since lining, the ponded water freezes, and ice remains in the canal throughout the winter. During winter water runs, ice collects at structures (bridges, siphons, etc.), restricting flow, which can cause water to overflow the canal banks. This problem was unanticipated. In the future, the possibility of ice jams should be considered when contemplating the rehabilitation (lining) of existing canals without adequate natural slope.

Reduced Capacity.—The Arnold Canal has problems with insufficient freeboard, especially in test sections A-1, A-2, A-7, and A-8 where the canal has been lined with 3 to 4 inches of shotcrete or grout-filled mattress lining. During construction of the test sections, efforts were made to maintain the existing freeboard; however, the available freeboard may have been reduced slightly. These freeboard problems have become more critical in recent years, as the district has increased deliveries from the historical 54 cfs to a new high of 64 cfs. Future lining installations should carefully consider the effect on available freeboard.

Sediment Cover.—Many of the exposed geomembranes are collecting sediment in the invert. This sediment may act as ballast against uplift, and may provide protection from UV and mechanical damage. Unknown if this sediment will improve design life.

Maintenance

To evaluate maintenance needs, the 27 test sections have been divided into four broad categories: Concrete, Concrete with Geomembrane Underliner, Exposed Geomembrane, and Spray-Applied Membrane. Concrete includes shotcrete, RCC, and grout filled mattress. Any of these concrete materials can also have a geomembrane underliner. The exposed geomembranes include HDPE, VLDPE, PVC, Hypalon, Teranap, and Exposed GCL. Finally, the spray-applied membranes include SPF with protective coating, Geotextile with protective coating, and Liquid Boot.

In general, the concrete liners are the best maintained because: (1) concrete needs the least maintenance, and (2) the districts are familiar with concrete and are comfortable performing the repairs. Conversely, the exposed geomembranes and spray-applied membranes need more repairs because of mechanical damage (animal traffic, maintenance equipment, vandalism, etc.), as well as UV attack. Also, field personnel are less familiar with geomembranes and, therefore, less likely to perform the required maintenance. Finally, special equipment is sometimes needed, such as an extrusion welder for HDPE and PP. Based on these findings, the following annual maintenance costs have been developed:

Concrete	$0.005 per square foot
Concrete with Geomembrane Underliner	$0.005 per square foot
Exposed Geomembrane	$0.010 per square foot
Spray-applied Membrane	$0.010 per square foot

The concrete maintenance cost is based on a two-man crew repairing a 1-mile section of 40-ft-wide canal in one 8-hour day at a total cost of $1,000. Annual maintenance consists of patching areas where concrete has broken loose. Cracks in the concrete lining would not be repaired. Geomembrane maintenance cost is based on patching all rips and tears in both exposed geomembranes and spray-applied membranes.

The irrigation district's maintenance activities for each test section are summarized in tables 7, 8, and 9. Note that many test sections need repairs that have not yet been performed.

Table 7.—Maintenance at Arnold Canal

#	Test section	Maintenance requirements	Maintenance performed	Additional maintenance needed
A-1	PE Geocomposite with Shotcrete cover	Minimal	None	Patch 4-5 small holes in shotcrete
A-2	30-mil VLDPE with Shotcrete cover	None	None	None
A-3	Exposed 80-mil HDPE	Minimal	Concrete Patch at 20+00	Patch 4-6 small tears in geomembrane
A-4	Exposed 30-mil PVC with geotextile UV cover	Minimal	Concrete Patch at 20+00 Concrete Patch at 20+20 Concrete Patch at 30+00	Sew 1000 ft of geotextile seams Repair tear in geomembrane at 20+31
A-5	Exposed 45-mil Hypalon with 16-oz geotextile cover	Minor	Concrete Patch at 30+00	Patch 1-2 small tears in geomembrane
A-6	Exposed 36-mil Hypalon with 8-oz geotextile cover	Minor	Patched 5-6 small tears in geomembrane	Patch several small tears in geomembrane
A-7	40-mil PVC with 3-inch grout-filled mattress	None	None	None
A-8	3-inch grout-filled mattress	Minimal	None	Patch grout mattress at 54+50
A-9	Exposed VLDPE with grout-filled mattress on side slopes only	Extensive	Concrete Patch at 55+00, Ballast over "whales." Removed Geomembrane from Invert	Test Section Abandoned at District's Request
A-10	Exposed HDPE with grout-filled mattress on side slopes only	Extensive	Removed Cement deposits, Ballast over "whales," Removed Geomembrane from Invert	Test Section Abandoned at District's Request

Table 8.—Maintenance at North Unit Main Canal

No.	Test section	Maintenance requirements	Maintenance performed	Additional maintenance needed
N-1	SPF with Futura 500/550 protective coating	Extensive	Removed washed-out foam at Siphon; Installed weed rack at Siphon	None - Replaced with RCC
N-2	SPF with Geothane 5020 protective coating	Extensive	Removed washed-out foam at Siphon; Installed weed rack at Siphon	None - Replaced with RCC
N-3	Tietex Geotextile with Geothane 5020 protective coating	Extensive	Patched holes in geotextile lining; Removed washed-out geotextile lining; Repaired damaged COI Pipe crossing	None - Replaced with RCC
N-4	Phillips Geotextile with Geothane 5020 protective coating	Extensive	Patched geotextile lining; Removed washed-out geotextile lining; Repaired damaged COI pipe crossing	None - Replaced with RCC
N-6	Shotcrete with Novocon Steel Fibers	Minor	Patched a couple of holes in Shotcrete; Removed large rocks; Caulked cracks in Shotcrete	Patch a couple of small holes in Shotcrete
N-7	Shotcrete with Phillips Polyfibers	None	None	Patch a couple of small holes in Shotcrete
N-8	Shotcrete with Fibermesh Polyfibers	None	None	Patch a couple of small holes in Shotcrete
N-9	Unreinforced Shotcrete	None	None	Patch a couple of small holes in Shotcrete

Table 9.—Maintenance at Tumalo, Lugert-Altus, and Juniper Flat Test Sections

No.	Test section	Maintenance requirements	Maintenance performed	Additional maintenance needed
T-1	Liquid Boot over an Existing Concrete Flume	Extensive	Completely disbonded in the invert	Replace with buried pipe
T-2	Liquid Boot over a Sandblasted Steel Flume	Minimal	Patched dozens of blisters, mostly in the invert	Patch additional blisters
T-3	Liquid Boot over a Broomed Steel Flume	Minimal	Patched dozens of blisters, mostly in the invert	Patch additional blisters
L-1	Exposed 160-mil Teranap Geomembrane	Moderate	Repaired 300-ft washout in 1996	None
J-1	Exposed 160-mil Teranap Geomembrane	Minimal	None	Need to repair 5 to 10 seams

Durability

Arnold Canal

Test Section A-1.—

Material:	4-mil Polyethylene (PE) Geocomposite with shotcrete cover
Description:	The Polyethylene Geocomposite is Phillips Petromat MB II, consisting of a 4-mil polyethylene geomembrane with a 4-oz nonwoven geotextile bonded to each side. The specified shotcrete thickness was 3 inches minimum; however, because of the irregular subgrade, the shotcrete averages 4 inches thick.
Construction cost:	4-mil PE Geocomposite with unreinforced shotcrete cover - $2.43 per square foot 4-mil PE Geocomposite with 1½-pound polyfiber shotcrete cover - $2.50 per square foot
Date Installed:	February 1992 (7 years old)
Location:	Station 0+00 to 10+00 (1,000 linear feet; 30,000 square feet)
Condition:	Excellent - After almost 7 years of service, the shotcrete lining is in excellent condition, completely protecting the underlying Polyethylene geocomposite liner from weathering and mechanical damage. The only significant damage is that the shotcrete cover is showing extensive cracking over the anchor trench where the shotcrete was tapered down to a thickness of less than 1 inch. Tapering of the shotcrete over the anchor trench is not recommended for future installations, instead, the shotcrete should maintain a minimum thickness of 2 inches over the anchor trench. No freeze-thaw damage has occurred. Most of the invert has standing water, typically 6 to 12 inches deep. A large amount of debris has collected in the canal, and two large sediment deposits were found. The first half of the test section (about 400 linear feet) is unreinforced and has significant transverse cracking (about every 20 feet), predominantly in the north (south-facing) sidewall. However, the cracks in the shotcrete are not considered detrimental because the geomembrane underliner provides the seepage control, while the shotcrete cover protects the geomembrane from weathering, ultraviolet light, mechanical damage, vandalism, and animal damage. Where not covered by standing water, random cracks are sometimes visible in the invert. Many of the cracks were previously marked with spray paint to aid in the detection of new cracks. Some new cracks develop every year, and many of the old cracks are growing in length but are not widening significantly. Crack width ranges from hairline to 1/16 inch. The second half of the test section (approximately 600 linear feet) contains 1½ lb/yd^3 polyfiber reinforcement, and fewer transverse cracks have developed in the sidewalls (about every 50 feet).

In March 1994, about 100 linear feet of this test section was torn out and replaced when the Highway 97 bridge at station 7+00 (estimated) was widened from two lanes to four. The new replacement lining uses the same construction materials and techniques as the old lining (Polyethylene Geocomposite with 3-inch shotcrete cover). This replacement liner is holding up well, and the amount of spalled shotcrete on the sidewalls under the new bridge has not progressed from the previous report. Costs for this lining replacement are not included in either the initial construction costs or in the maintenance costs. A tree fell onto this test section during a windstorm in November 1994, but caused no damage to the shotcrete lining. An exposed geomembrane lining would not have fared as well.

Maintenance: Minimal maintenance required to date

Performed: None

Needed: Patch a couple of holes in the shotcrete lining (at the waterline) at the downstream end of this test section (approximately station 9+00).

Photographs: 79 through 82

Arnold Canal - Test Section A-1
4-mil Polyethylene Geocomposite with Shotcrete Cover

Photograph 79.—Excellent condition after 7 years of service - shotcrete in the first 400-ft section is unreinforced.

Photograph 80.—Excellent condition after 7 years of service - shotcrete in the second 600-ft section is reinforced with polyfibers.

Arnold Canal - Test Section A-1
4-mil Polyethylene Geocomposite with Shotcrete Cover

Photograph 81.—Random cracks are visible in the invert as well as in the sidewalls.

Photograph 82.—Shotcrete lining in tunnel beneath the new bridge has spalled in some locations, but spall is not progressing.

Test Section A-2.—

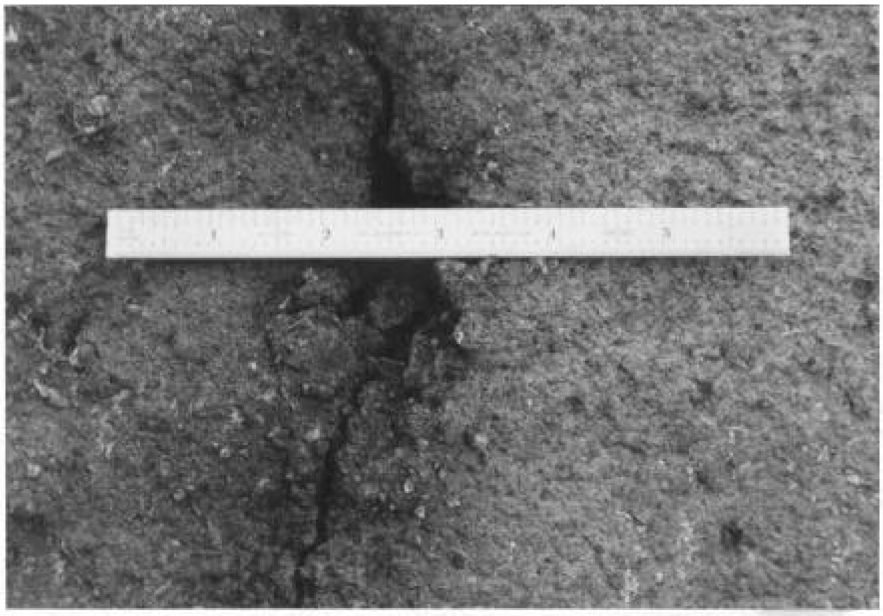
Material:	30-mil textured VLDPE with 16-oz geotextile cushion and shotcrete cover
Description:	The VLDPE liner is 30-mil Gundle textured Hyperelastic. The geotextile cushion is Polyfelt TS-1000, a 16-oz, needle-punched, nonwoven geotextile. The specified shotcrete thickness was 3 inches minimum; however, because of the irregular subgrade, the shotcrete averages 4 inches thick.
Construction Cost:	$2.52 per square foot
Date Installed:	October 1992 (6½ years old)
Location:	Station 10+00 to 15+00 (500 linear feet, 15,000 square feet)
Condition:	Excellent - The shotcrete lining is in excellent condition, completely protecting the underlying VLDPE geomembrane. After 6½ years, no freeze-thaw damage has been observed. Most of the invert is covered with standing water up to 18 inches deep. Little to no sediment has collected in the canal invert. Dozens of transverse contraction cracks have developed on each bank (every 10 to 20 feet). Cracks range from hairline to 3/16 inch wide. Cracking in the thin, tapered shotcrete over the anchor trench is moderate to severe. Tapering of the shotcrete over the anchor trench is not recommended for future installations; instead, the shotcrete should maintain a minimum thickness of 2 inches over the anchor trench.
Maintenance:	No maintenance requirements to date Performed: None Needed: None
Photographs:	83 through 86

Arnold Canal - Test Section A-2
30-mil textured VLDPE with 16-oz Geotextile Cushion and Shotcrete Cover

Photograph 83.—Canal overview - Excellent condition after 6½ years of service.

Photograph 84.—Transverse contraction cracks are visible on the sidewalls.
Red spray paint from 1996 inspection shows that number
and length of cracks have increased.

Arnold Canal - Test Section A-2
30-mil textured VLDPE with 16-oz Geotextile Cushion and Shotcrete Lining



Photograph 85.—Largest cracks measure up to 3/16 inch wide.

Photograph 86.—Thin shotcrete over anchor trench is less than 1 inch thick and severely cracked.

Test Section A-3.—

Material: Exposed 80-mil Textured HDPE

Description: HDPE liner is Gundle 80-mil textured Gundline HDT

Construction Cost: $1.38 per square foot

Date Installed: October 1992 (6½ years old)

Location: Station 15+00 to 20+00 (500 linear feet; 15,000 square feet)

Condition: Very Good - After 6½ years of service, the exposed HDPE liner is in very good condition, with only minor mechanical damage. About half of this test section has standing water (typically 6 to 12 inches deep), with little to no sediment in the invert. A small tear at the upstream end (station 15+00) is probably from a backhoe removing the dike after the postconstruction ponding tests. A small (3-inch-long) tear or cut was found in the invert (station 16+00). A semicircular tear (perhaps from an animal hoof) is present on the left bank above the waterline (station 18+50). The anchor trench on the left bank is holding up well. The rock cover (in lieu of an anchor trench) on the right bank is also performing satisfactorily. Little freeboard is available on the right bank; however, the extra HDPE beneath the rock cover could be used to increase the freeboard if needed. At station 19+80 (estimated), the HDPE is torn where stretched tightly over a rock. The stainless steel battens at the bridge (station 17+50) are in excellent condition. The battens measure 2 inches wide by 3/16 inches thick, cover a thin rubber gasket, and have anchor bolts on 6-inch centers. The degree of HDPE texturing ranges from quite rough to almost smooth.

Maintenance: Minimal maintenance required to date

Performed: In 1994, the district placed a concrete anchor pad between test sections A-3 and A-4 at station 20+00

Needed: Patch half a dozen small tears in the liner. District needs a small hand-held extrusion welder to perform repairs.

Photographs: 87 and 88

Arnold Canal - Test Section A-3
Exposed 80-mil Textured HDPE

Photograph 87.—Canal overview - Very good condition after 6½ years of service. Note the high waterline shows little available freeboard.

Photograph 88.—Tears in the liner at station 16+00.

Test Section A-4.—

Material: Exposed 30-mil PVC with Geotextile UV Cover

Description: The geomembrane is Geolam geocomposite, consisting of 30-mil Occidental PVC geomembrane bonded to a Trevira 6-oz needle-punched, nonwoven geotextile. The Geolam is installed with the bonded geotextile facing up to provide UV protection for the PVC geomembrane. A second nonbonded layer of Trevira 1120 6-oz geotextile acts as a cushion beneath the PVC geomembrane.

Construction Cost: $1.05 per square foot

Date Installed: March 1992 (7 years old)

Location: Station 20+00 to 30+00 (1,000 linear feet; 30,000 square feet)

Condition: Very Good - actually performing much better than expected. The PVC is holding up well with no visible deterioration or stiffening, even where exposed. The PVC may be experiencing a slight color change from gray to white where exposed above the waterline. The four longitudinal PVC seams look great and are almost all below the waterline. The geotextile is slowly weathering away (especially where unbonded at seams). The most severe weathering is above the waterline. About 25 percent of the geotextile seams need to be repaired by sewing. Seaming of the geotextile with hog-rings has proven to be only partially effective.

A significant amount of sediment (up to 12 inches) and trash has collected in the invert, especially between stations 23+00 and 27+00. Aquatic vegetation is growing in the sediment.

The subgrade is quite rough, and a number of pointed rock stress concentrations can be seen in the geomembrane. Backhoe tears (from removing the dike after ponding tests) have been repaired with a 10-foot by 10-foot concrete patch at station 20+20. In November 1994, a tree fell into the canal during a wind storm and punctured the liner at station 20+20, causing a small tear (1 foot by 1 foot) which needs to be repaired to prevent water from getting under the liner. A small hole at station 28+50 has been repaired with a 1-foot by 1-foot concrete patch.

Maintenance: Minor maintenance required to date

Performed: In 1994, the district placed concrete anchor pads at stations 20+00 and station 30+00. The district also repaired one small hole at station 28+50 (by placing a 1-ft by 1-ft-concrete cap over the tear) and placed a 10-foot by 10-foot concrete pad in the invert at 20+20 to repair backhoe damage.

Needed: About 1,000 feet of geotextile seams need to be sewn to protect PVC geomembrane from UV degradation. Need to repair a small tear in the liner at 20+20. Repairs can be made to PVC using PVC solvent cement and extra PVC geomembrane.

The district plans to remove sediment to improve flow. Great care should be taken to prevent damage to the exposed geomembrane during canal cleaning.

Photographs: 89 through 94

Arnold Canal - Test Section A-4
Exposed 30-mil PVC with Geotextile UV Cover

Photograph 89.—Canal overview - Very good condition after 7 years of service.

Photograph 90.—Exposed PVC geomembrane where the geotextile seam needs repair.

Arnold Canal - Test Section A-4
Exposed 30-mil PVC with Geotextile UV Cover

Photograph 91.—Tear in geomembrane (from falling tree) at station 20+20 needs repair.

Photograph 92.—At the top of the canal bank, the geotextile is deteriorating from UV exposure.

Arnold Canal - Test Section A-4
Exposed 30-mil PVC with Geotextile UV Cover

Photograph 93.—Closeup of deteriorating geotextile above the waterline. PVC geomembrane is visible beneath deteriorating geotextile.

Photograph 94.—A great deal of sediment has collected in the canal around this bend between stations 23+00 and 27+00.

Test Section A-5.—

Material: Exposed 45-mil Hypalon with 16-oz Geotextile Cushion

Description: The Hypalon membrane is JP Stevens 45-mil reinforced CSPE (Chlorosulfanated polyethylene). The geotextile cushion is Polyfelt TS-1000, a 16-oz, needle-punched, nonwoven geotextile.

Construction Cost: $1.11 per square foot

Date Installed: March 1992 (7 years old)

Location: Station 30+00 to 35+00 (500 linear feet; 15,000 square feet)

Condition: Very Good - After 7 years, the exposed Hypalon geomembrane and longitudinal seams are holding up well. Standing water covers almost the entire invert, typically 6 to 12 inches deep. The majority of the test section has 1 to 4 inches of sediment, with a small amount of vegetation growing in the sediment. The upstream transition between Test Sections 4 and 5 (station 30+00) has been covered with a 7-foot concrete cap, which is working well. A No. 4 rebar has been driven through the Hypalon liner on the top of the left bank at station 31+00, but is well above the waterline. A couple of small tears have developed at the anchor trench (stations 31+00 left and 33+00 right), and a sharp subgrade rock has punctured the liner at the waterline (station 33+20). The right canal bank is unstable and has noticeable sloughing beneath the liner (approximately stations 33+00 to 33+50). As with all the test sections, most of the damage to date has been mechanical damage caused by man.

Maintenance: Minor maintenance required

Performed: In 1994, the district placed a concrete anchor pad at the upstream end (station 30+00).

Needed: Patch a couple of small tears in the geomembrane.

Again, the district plans to remove sediment to improve flow. Great care should be taken to prevent damage to the exposed geomembrane during canal cleaning.

Photographs: 95 through 98

Arnold Canal - Test Section A-5
Exposed 45-mil Hypalon with 16-oz Geotextile Cushion

Photograph 95.—Canal overview - Very good condition after 7 years of service.

Photograph 96.—Sharp subgrade rock (or stick) has punctured the liner at station 33+20. The puncture has not progressed over the last 4 years.

Arnold Canal - Test Section A-5
Exposed 45-mil Hypalon with 16-oz Geotextile Cushion

Photograph 97.—Sloughing of the embankment beneath geomembrane liner (station 33+00 to 35+50).

Photograph 98.—Two small tears near the anchor trench.

Test Section A-6.—

Material: Exposed 36-mil Hypalon with Bonded 8-oz Geotextile Cushion

Description: The geomembrane is JP Stevens Terra-Tuff 801-R geocomposite, consisting of 36-mil reinforced Hypalon laminated to an 8-oz nonwoven polyethylene terephthalate (PET) Geotextile Cushion.

Construction Cost: $1.03 per square foot

Date Installed: March 1992 (7 years old)

Location: Station 35+00 to 40+00 (500 linear feet; 15,000 square feet)

Condition: Very Good - After 7 years, the exposed Hypalon geomembrane and longitudinal seams are holding up well. Standing water covers most of the invert, typically 6 to 12 inches deep. The majority of the canal has 1 inch or less of sediment; some vegetation is growing underwater. The upstream transition between Test Sections 5 and 6 (station 35+00) has a transverse Hypalon/Hypalon seam which is in good condition. A concrete cap at this location would facilitate future ponding tests.

A small tear in the Hypalon at the anchor trench (station 35+00 left) needs to be repaired. Five or six small tears in the invert were patched in Spring 1994 around the golf course turnout at station 35+50. All the patches look good and are holding up well. At station 39+90, a large tear on the left bank (probably caused by a backhoe during dike removal) needs to be repaired. A couple of survey stakes were found at the top of the bank on the left side. At station 39+95, several large cuts were made to relieve trapped water. These cuts allow some water to leak out of the canal, but they also allow any water trapped beneath the liner to escape. These tears need to be repaired to more fully evaluate the performance of the exposed hypalon liners. At station 40+00, the Terra-Tuff liner is connected to the adjacent grout-filled mattress (Test Section 7) by batten strips, which are functioning satisfactorily. In the future, any dikes built between Test Sections 6 and 7 should be constructed on the grout-filled mattress in Test Section 7, not on the exposed hypalon in Test Section 6.

Maintenance: Minor maintenance required to date

Performed: None

Needed: Patch several small tears and cuts, especially at the downstream transition. Again, the district plans to remove sediment to improve flow, and great care should be taken to prevent damage to the exposed liner.

Photographs: 99 and 100

Arnold Canal - Test Section A-6
Exposed 36-mil Hypalon with Bonded 8-oz Geotextile Cushion

Photograph 99.—Canal overview - Very good condition after 7 years of service.

Photograph 100.—Several tears at the downstream end (station 40+00) need to be repaired.

Test Section A-7–

Material: 40-mil PVC with 3-inch Grout-filled Mattress

Description: 40-mil Occidental Oxyflex PVC membrane covered with Nicolon Armorform 3-inch Uniform Section Mat (USM) grout-filled mattress

Construction Cost: $2.54 per square foot

Date Installed: November 1991 (7½ years old)

Location: Station 40+00 to 48+00 (800 linear feet; 24,000 square feet)

Condition: Excellent - After 7½ years, the grout-filled mattress is in excellent condition, with only small occasional defects. The grout-filled mattress is completely protecting the underlying PVC geomembrane. No freeze-thaw damage is evident. The mattress is fairly uniformly grouted in spite of the uneven rocky subgrade. A small amount of cement paste (no aggregate) is present in the invert between the concrete "bricks." The first 500 feet of this test section have a significant amount of sediment (up to 1 foot deep) and 6 to 12 inches of standing water. The second 300 feet has no sediment and no standing water, suggesting higher velocities and slope to drain. The outer fabric of the grout mattress is starting to deteriorate (estimate 5 to 10 percent is gone). Where not grouted above the waterline, the geotextile is quite weak and tears easily. At station 46+00, the mattress was installed over a subgrade rock, and the grout was only about ½ inch thick. The grout and geotextile have worn away, and the underlying PVC membrane is visible.

Maintenance: Minor maintenance required to date

Performed: None

Needed: Repair a couple of small holes in grout mattress. Recommend patching with concrete.

Again, the district plans to remove sediment to improve flow. As the geomembrane is protected by the grout mattress, damage to the underlying geomembrane is not a concern.

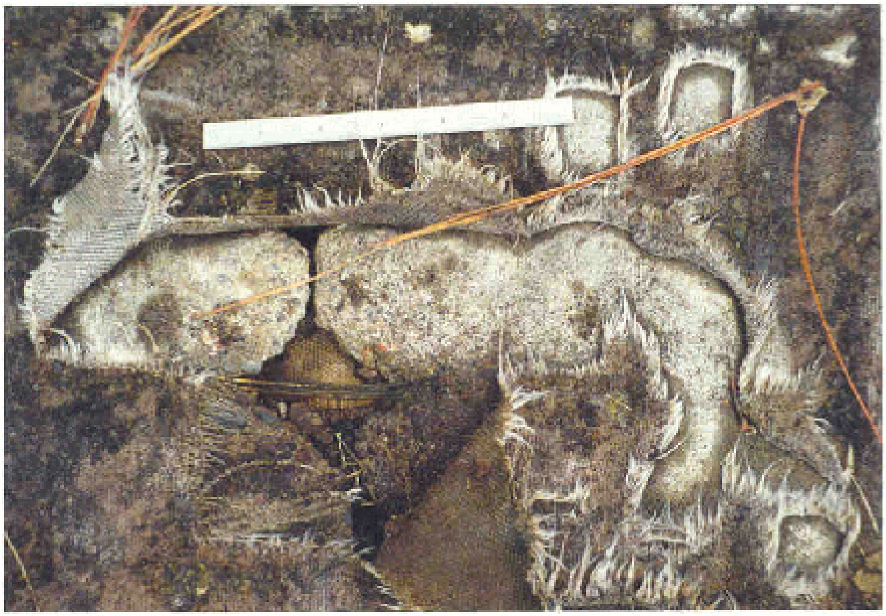
Photographs: 101 through 104

Arnold Canal - Test Section A-7
40-mil PVC with 3-inch Grout-filled Mattress

Photograph 101.—Canal overview - Excellent condition after 7 years of service. The first 500 feet of this test section has a significant amount of sediment and standing water.

Photograph 102.—Geotextile is deteriorating and is abraded completely in some areas.

Arnold Canal - Test Section A-7
40-mil PVC with 3-inch Grout-filled Mattress



Photograph 103.—Closeup of area with deteriorated geotextile. Note that some of the grout bricks are also missing in this area.

Photograph 104.—PVC membrane visible beneath grout mattress. Grout was only about ½ inch thick in this location.

Test Section A-8.—

Material: 3-inch Grout-filled Mattress

Description: The grout-filled mattress is Nicolon Armorform 3-inch Uniform Section Mat (USM)

Construction Cost: $1.92 per square foot

Date Installed: November 1991 (first 200 feet) 7½ years old
November 1992 (500 additional feet) 6½ years old

Location: Station 48+00 to 55+00 (700 linear feet; 21,000 square feet)

Condition: Excellent - After 7 years, the grout-filled mattress is in excellent condition after 3½ years of service, with no freeze-thaw damage. The first 200 feet with zippered seams has a much neater appearance than the second 500 feet with sewn seams. Both areas are uniformly grouted in spite of the uneven rocky subgrade. A small amount of cement paste is present in the invert between the concrete "bricks." Except for one area of sediment at station 52+00, no sediment or standing water is present in the invert, suggesting higher velocities and a steeper slope through this test section. The slope visibly increases past the bridge (station 49+50). The grout-filled mattress is well tied in to the bridge, with no gaps that would allow seepage. The outer fabric of the grout mattress is starting to show deterioration, especially at station 54+50 (left bank) where several concrete "bricks" are missing.

Maintenance: Minimal maintenance required to date

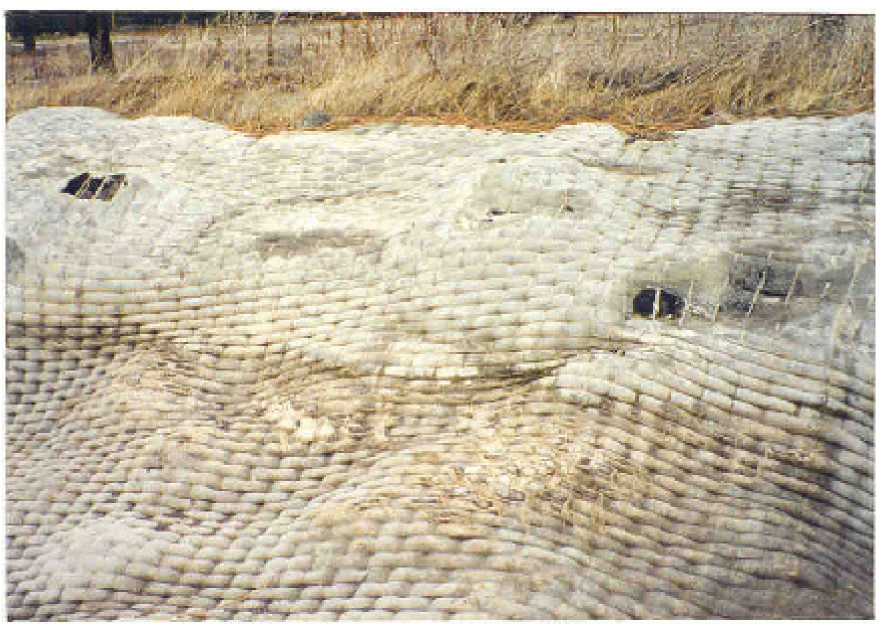
Performed: None

Needed: Patch the grout mattress at station 54+50.

Photographs: 105 and 106

Arnold Canal - Test Section A-8
3-inch Grout-filled Mattress

Photograph 105.—Canal overview - Excellent condition after 7 years of service.



Photograph 106.—The grout-filled mattress is missing several bricks at station 54+50.

Test Sections A-9 and A-10.—

Material: Test Section A-9 is 60-mil VLDPE with 12-oz Geotextile Cushion and 3-inch grout-filled mattress on side slopes only

Test Section A-10 is 60-mil HDPE with 12-oz Geotextile Cushion and 3-inch grout-filled mattress on side slopes only

Description: The VLDPE is 60-mil Poly-America Dura-flex, and the HDPE is 60-mil Poly-America Poly-flex. The geotextile cushion is Amoco 4512 (12-oz needle-punched, nonwoven geotextile). The grout-filled mattress is Nicolon Armorform.

Construction Cost: $1.79 per square foot

Date Installed: November 1992 (removed from study after 28 months)

Location: Station 55+00 to 65+00 (1,000 linear feet; 30,000 square feet)
Station 65+00 to 75+00 (1,000 linear feet; 30,000 square feet)

Condition: **(Removed from study)** after 28 months - In March 1995, the geomembrane liners were removed from the invert. The grout-filled mattress on the side slopes was left in place. The subgrade beneath the geomembrane liners was very rocky with little bedding material. Much of the imported bedding material probably washed away during canal operation.

Liner "whales" caused problems in these test sections from the first water run. Several attempts were made to repair this test section, but none were successful. Unfortunately, the cause of the "whales" was never resolved. Volcanic gases are suspected to be the cause.

Maintenance: Extensive maintenance required to date

Performed: In 1994, Polyflex and Canamer repaired 20 to 30 small tears in test sections A-9 and A-10, and the district placed concrete parking blocks and riprap over "whales." The district also placed a concrete pad over the transition between test sections 8 and 9 (station 55+00). In 1995, the contractor removed all the exposed geomembrane from the invert on test sections A-9 and A-10.

Needed: Test sections abandoned after 28 months at district' request.

Photographs: 107

Arnold Canal - Test Sections A-9 and A-10
60-mil VLDPE (or HDPE) with 12-oz Geotextile Cushion and 3-inch Grout-filled Mattress on Side Slopes Only

Photograph 107.—Canal overview - Removed from study after 2½ years of service. Geomembrane liner in the invert was removed in spring 1995 because of liner “whales” impeding flow.

North Unit Main Canal

Test Sections NU-1 and NU-2.—

Material: Spray-applied Polyurethane Foam (SPF) with Futura 500/550 protective coating

SPF with Geothane 5020 protective coating

Description: SPF is 2 inches of 2-pound (lb/ft^3) foam covered with about ½ inch of 5-pound foam. Total protective coating thickness is 50 to 55 mils.

Construction Cost: $4.33 per square foot

Date Installed: October 1992 through March 1993 (6½ years old)
October 1992

Location: Station -2+00 to 1+00 (300 linear feet, 18,000 square feet)
Station 1+00 to 4+00 (300 linear feet, 18,000 square feet)

Condition: During the first couple of irrigation seasons, large sections of foam began washing out in the invert. Over the years, additional foam continued to washout. See "Year 5 Durability Report (Swihart et al., 1997).

(Removed from study) - Replaced with RCC in the invert (1998) and shotcrete on the side slopes (1999).

Test Sections NU-3 and NU-4.—

Material: Tietex geotextile with spray-applied Geothane 5020 protective coating
Phillips geotextile with spray-applied Geothane 5020 protective coating

Description: Tietex is a 6-oz woven geotextile. Phillips Roof-on E-6N is a 6-oz needle-punched, nonwoven geotextile. Total protective coating thickness is 60 mils.

Construction Cost: $2.64 per square foot

Date Installed: October 1992 (complete failure after first filling)

Location: Station 4+00 to 7+00 (300 linear feet; 18,000 square feet)
Station 7+00 to 10+00 (300 linear feet; 18,000 square feet)

Condition: Complete failure - Sections of the geotextile liners washed out the first time the canal was filled with water (spring 1993). The geotextiles tore at the foam anchor trench, and several large sections of geotextile washed downstream, damaging a pipeline crossing. The irrigation district previously removed all remaining liner in these two test sections. See the "2-Year Durability Report" for further details.

(Removed from study) and replaced with RCC invert (1998) and shotcrete side slopes (1999).

Maintenance: Extensive repairs were required before removal.

Test Sections NU-6 through NU-9.— General comments apply to all four shotcrete sections.

Material: Shotcrete **-** The specified shotcrete thickness was 3 inches minimum. Because of the irregular rocky subgrade, the actual shotcrete thickness is highly variable and averages about 5 inches.

Date Installed: February 1992 (7 years old)

Condition: Excellent - All the shotcrete is in excellent condition. No obvious visible differences exist in the performance of the four shotcrete test sections. No freeze-thaw damage is evident after 7 years of service. A large pond just upstream from the drop structure (station 27+80) indicates a low seepage rate. Small ponds are present on all four test sections.

Contraction cracks on the sidewalls have developed every 100 to 200 feet. Crack width varies from hairline to 1/8 inch. Cracks do not extend completely across the canal prism but, instead, usually disappear somewhere in the sidewall or invert. Cracks are more evident during cold weather. Cracks grow in length and numbers with time but do not seem to widen significantly.

Some small holes were found in the shotcrete over voids up to 4 inches in depth. Numerous partially exposed rocks were discovered with little to no shotcrete cover.

The thickness of the shotcrete is variable because of normal problems with field installation quality control. A couple of holes developed and were patched. At these locations, the shotcrete was found to be very thin (less than 1 inch). Further holes continue to develop in thin areas.

The areas where the flow prism is constricted, and where the velocity increases, show a small amount of exposed aggregate in the invert caused by erosion of the surface cement. This abrasion does not appear to be severe.

Many large rocks (typically 12 inches in diameter) are collecting in the canal invert (perhaps rolled in by local youths). Vegetation is growing out of cracks in the shotcrete near the top of side slopes.

Test Section NU-6.—

Material: Shotcrete reinforced with Novocon steel fibers

Description: Steel fibers are 1½-inch Novocon crimped fibers (Novocrimp)

Construction Cost: \$2.33 at a fiber dosage of 50 lb/yd^3
\$2.20 at a fiber dosage of 25 lb/yd^3

Date Installed: February 1992 (7 years old)

Location: Station 20+00 to 25+00 (500 linear feet; 30,000 square feet)

Condition: Excellent - Shotcrete performing well after 7 years of service. Test section has some cracking, voids, exposed subgrade rocks, and vegetation typical of all the shotcrete test sections.

On the left bank (on this test section only), the contractor brought in soil to fill voids in the irregular subgrade before shotcreting. However, the imported silty material washed out during shotcreting, resulting in some voids under the shotcrete surface. A couple of 1- to 2-foot-diameter holes developed in the shotcrete. In both cases, the shotcrete was found to be only about 1 inch thick. Additional holes continue to develop where the shotcrete is thin and not well supported over voids in the subgrade.

Steel fibers visible on the shotcrete surface are corroded, rust-brown in color, and very weak (break easily when bent by hand). However, steel fibers within the shotcrete are shiny bright and show no sign of corrosion. No differences were noted between the first 250-ft section containing 50 pounds of steel fibers per cubic yard of shotcrete and the second 250-ft section with 25 pounds per cubic yard..

Maintenance: Minimal maintenance required to date

Performed: Just prior to the 1994 ponding test, the district performed some minor repairs, including patching a couple of small holes in the shotcrete and sealing about 60 feet of transverse cracks with elastomeric sealant.

Needed: Patch several small holes in the shotcrete lining.

Photographs: 108 through 113

North Unit Canal - Test Section NU-6
Shotcrete Reinforced with Novocon Steel Fibers

Photograph 108.—Canal overview - Excellent condition after 7 years of service.

Photograph 109.—Transverse crack on side slope now extends
into the invert for a total length of about 30 feet.
Ditchrider pointing at end of crack in the invert.

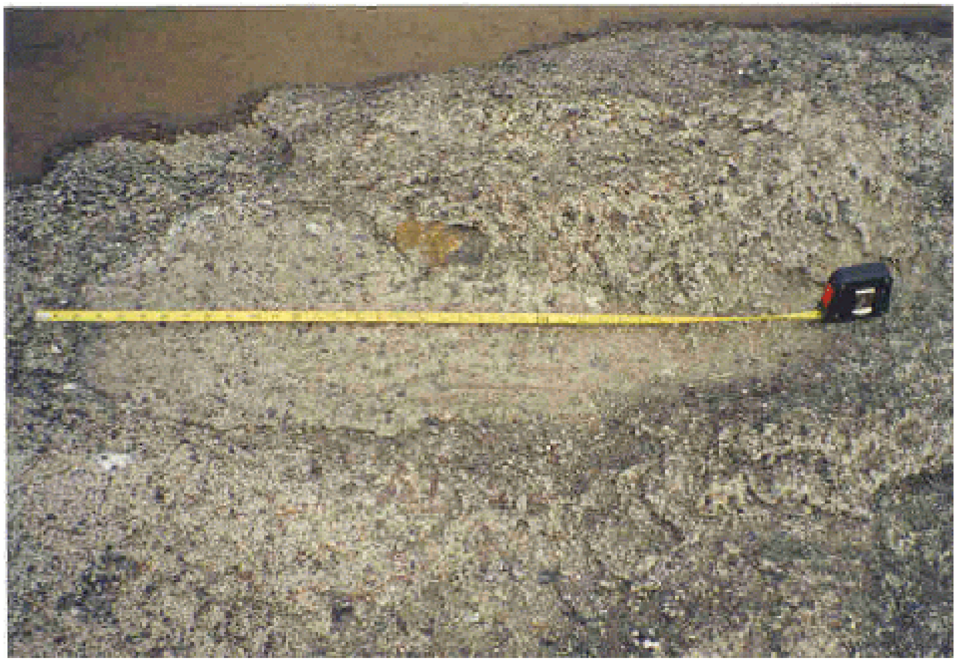
North Unit Canal - Test Section NU-6
Shotcrete Reinforced with Novocon Steel Fibers

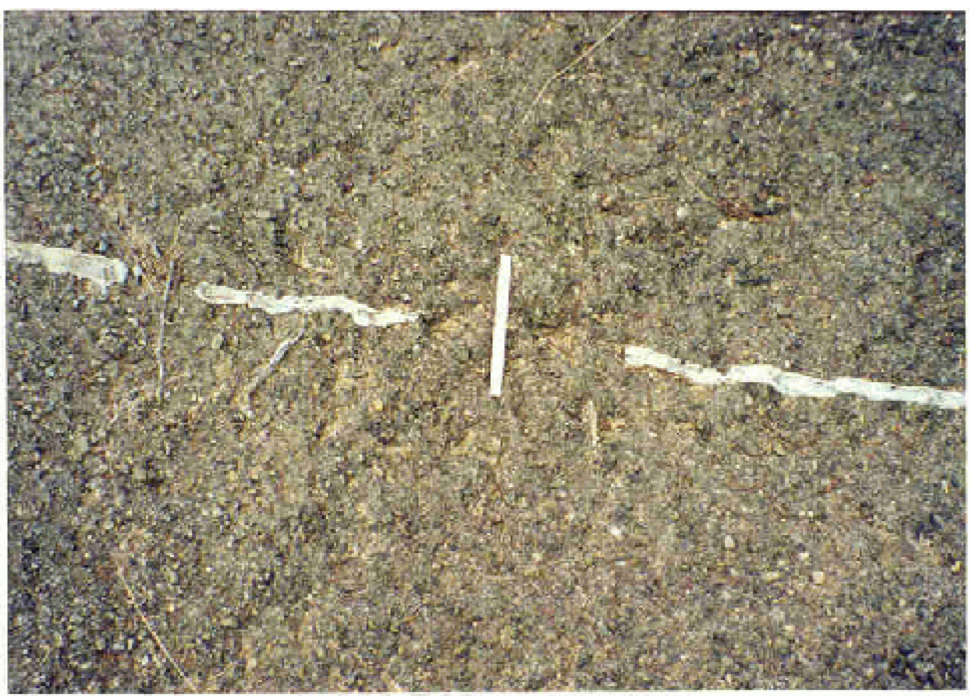
Photograph 110.—Area at top of canal lining where subgrade is washing out behind lining.

Photograph 111.—12-inch-diameter hole in shotcrete lining.
Shotcrete is less than 1 inch thick at this location.

North Unit Canal - Test Section NU-6

Shotcrete Reinforced with Novocon Steel Fibers





Photograph 112.—A previous 2-ft-diameter repair is still in good condition.

Photograph 113.—Elastomeric sealant has disbonded in many areas.

Test Section NU-7.—

Material: Shotcrete reinforced with Phillips polyfibers

Description: Polyfibers are ¾-inch Phillips Fi-con polypropylene fibers

Construction Cost: \$2.21 per square foot at fiber dosage of 3 lb/yd^3
\$2.14 per square foot at fiber dosage of 1½ lb/yd^3

Date Installed: February 1992 (7 years old)

Location: Station 25+00 to 30+00 (500 linear feet; 30,000 square feet)

Condition: Excellent - Shotcrete performing well after 7 years of service. Test section has some cracking, voids, exposed subgrade rocks, and vegetation typical of all the shotcrete test sections.

Polyfibers are visible on the shotcrete surface. No differences were noted between the first 250-foot section containing 3 pounds of polyfibers per cubic yard of shotcrete and the second 250-foot section with 1.5 pounds per cubic yard.

Maintenance: Minimal

Performed: None

Needed: Patch a couple of small holes in the shotcrete.

Photographs: 114 through 116

North Unit Canal - Test Section NU-7
Shotcrete Reinforced with Phillips Polyfibers

Photograph 114.—Canal overview - Excellent condition after 7 years of service.

Photograph 115.—Two-ft diameter hole in shotcrete lining.
Note that the shotcrete is only about ½ inch thick in this location.

North Unit Canal - Test Section NU-7
Shotcrete Reinforced with Phillips Polyfibers

Figure 116.—Void beneath small hole in shotcrete lining is about 6 inches deep. Extent of void is unknown.

Test Section NU-8.—

Material: Shotcrete reinforced with Fibermesh Polyfibers

Description: Polyfibers are Fibermesh Harbourite 320 (3/4-inch-long fibrillated polypropylene fibers).

Construction Cost: \$2.21 per square foot at a fiber dosage of 3 lb/yd^3
\$2.14 per square foot at a fiber dosage of 1½ lb/yd^3

Date Installed: February 1992 (7 years old)

Location: Station 30+00 to 35+00 (500 linear feet: 30,000 square feet)

Condition: Excellent - The shotcrete is performing well after 7 years of service.

Test section has some cracking, voids, exposed subgrade rocks, and vegetation typical of all shotcrete installations. Polyfibers are visible on the shotcrete surface. No visible differences have been noted between the first 250-ft section containing 3 pounds of polyfibers per cubic yard of shotcrete and the second 250-ft section with 1.5 pounds per cubic yard.

Maintenance: Minimal maintenance required to date

Performed: None

Needed: Patch a couple of small holes in shotcrete.

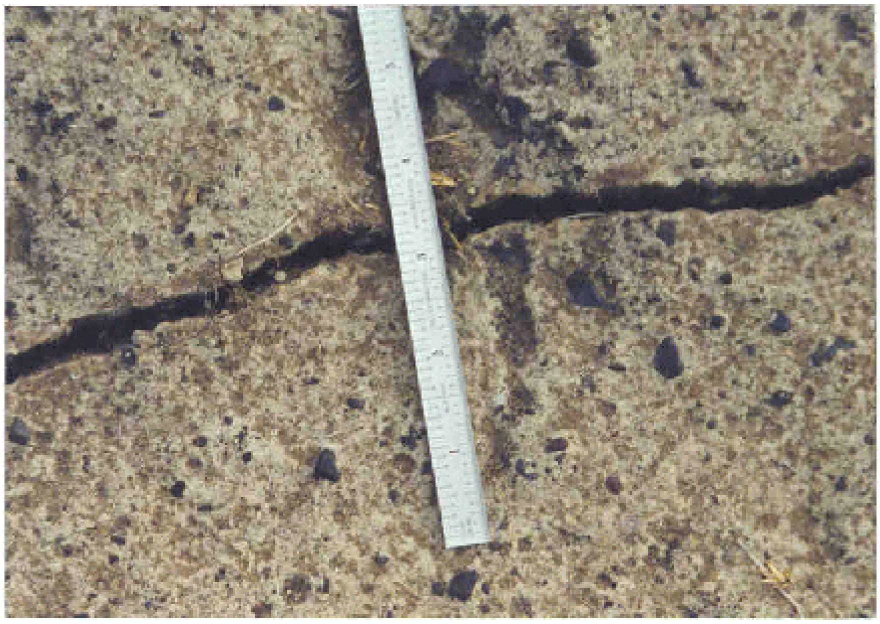
Photographs: 117 through 119

North Unit Canal - Test Section NU-8
Shotcrete Reinforced with Fibermesh Polyfibers

Photograph 117.—Canal overview - Excellent condition after 7 years of service.

Photograph 118.—Extent of random cracking at this location has not increased over the last few years.

North Unit Canal - Test Section NU-8
Shotcrete Reinforced with Fibermesh Polyfibers



Photograph 119.—Largest crack measures about ¼ inch wide.

Test Section NU-9.—

Material: Unreinforced shotcrete

Construction Cost: $2.07 per square foot

Date Installed: February 1992 (7 years old)

Location: Station 35+00 to 40+00 (500 linear feet; 30,000 square feet)

Condition: Excellent - Shotcrete performing well after 7 years of service.

Test section has some cracking, voids, exposed subgrade rocks, and vegetation typical of all the shotcrete installations. A couple of holes have developed in the shotcrete at the downstream end.

Maintenance: No maintenance required to date

Performed: Minimal

Needed: Patch a couple of small holes in the shotcrete.

Photographs: 120 through 122

North Unit Canal - Test Section NU-9
Unreinforced Shotcrete

Photograph 120.—Canal overview - Excellent condition after 7 years of service.

Photograph 121.—Several holes in shotcrete, exposing subgrade rocks on sidewall.

North Unit Canal - Test Section NU-9
Unreinforced Shotcrete

Photograph 122.—Closeup of 1-ft-diameter hole in shotcrete lining.
Shotcrete is less than 1 inch thick.

Tumalo - Bend Feed Canal

Test Section T-1.—

Material: Liquid Boot over an existing concrete flume

Description: Liquid Boot is a spray-applied, neoprene-polymer-modified asphalt emulsion.

Construction Cost: $1.70 per square foot

Date installed: April 1994 (5 years old)

Location: Bend Feed Canal Headworks (75 linear feet; 1,575 square feet)

Condition: **(Removed from Study) -** Replaced with Buried Pipe in 1999

The Liquid Boot was completely disbonded from the 11-foot invert and mostly washed away. The remaining Liquid Boot in the invert had rolled up into the corners against the sidewalls. Liquid Boot on the 5-foot vertical sidewalls was still intact, well bonded, and flexible.

Several changes in the construction process have been identified that might have increased the likelihood for success of this test section. A cutoff trench would have tied down the leading edge. Sandblasting would have improved the bond of the Liquid Boot to the concrete. Coating the sidewalls one day, and the invert the next, would have minimized the amount of water from the emulsion that accumulated in the invert. Finally, greater care could have been taken to minimize foot traffic in the invert during construction.

Maintenance: Extensive maintenance was required prior to removal.

Test Section T-2.—

Material: Liquid Boot over a sandblasted steel flume

Description: Liquid Boot is a spray-applied, neoprene-polymer-modified asphalt emulsion.

Construction Cost: $2.16 per square foot

Date installed: April 1994 (5 years old)

Location: Flume Number 4 - Bend Feed Canal (463 linear feet; 7,871 square feet)

Condition: Very Good - The Liquid Boot is well bonded to 99 percent of the steel flume. No leakage is evident. Difficult to inspect because of 6 to 12 inches of standing water. Several blisters (50+) have developed in the Liquid Boot, directly over the old tar material in the seams between the flume's 3-foot-wide steel panels. The majority of the blisters are in the bottom of the invert, except for a few, located 1 to 2 feet up the side. The blisters typically measure 6 inches in diameter, with the largest measuring 6 inches across by 24 inches long. The blisters are full of sand and sediment. Apparently, the Liquid Boot is poorly bonded to the old tar material, and the Liquid Boot deforms and blisters under the force of the flowing water. Once a small hole develops in the blister, the flowing water deposits sand and debris, causing the blister to grow in size. The water released from the Liquid Boot emulsion during construction probably contributed to the poor bond in the invert. Finally, the blisters are more prevalent in the downstream, shaded end of the flume. During construction, the cooler temperatures in the shaded areas might have retarded cure and weakened the bond. The geotextile embedded in the Liquid Boot at the cleanout drain is partially disbonded but in fair condition. The Liquid Boot has disbonded from the concrete at the upstream and downstream transitions.

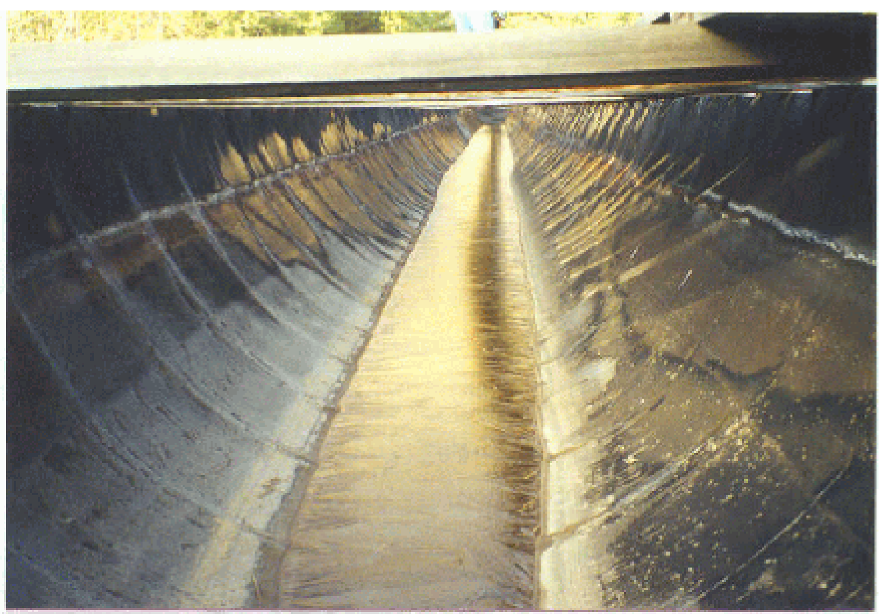
After this test section, the Liquid Boot manufacturer (LBI) made several modifications to the construction process. A light tack coat of the "A" component improves the bond of the Liquid Boot. Also, bond in the invert can be improved by coating the sidewalls first, then coating the invert after the water released from the Liquid Boot on the sidewalls has evaporated.

Maintenance: Minor maintenance is required at this time. The district needs to cut open the blisters, trim away any unbonded material, then patch with Liquid Boot Trowel Grade. The district has been using a single-part roofing tar for minor repairs, which they report is much easier to use than the 2-part Liquid Boot Trowel Grade with equivalent performance.

Photographs: 123 through 126

Tumalo Irrigation District - Test Section T-2
Liquid Boot over a Sandblasted Steel Flume

Photograph 123.—Flume overview - Very good condition after 5 years of service, with no leaks.



Photograph 124.—Inside the flume.

Tumalo Irrigation District - Test Section T-2
Liquid Boot over a Sandblasted Steel Flume

Photograph 125.—Large blister in the invert.

Photograph 126.—Liquid Boot and geotextile used at the cleanout drain are holding up well.

Test Section T-3.—

Material: Liquid Boot over a broomed steel flume

Description: Liquid Boot is a spray-applied, neoprene-polymer-modified asphalt emulsion.

Construction Cost: $1.40 per square foot

Date Installed: April 1995 (4 years old)

Location: Klippel Flume - Bend and Webber Canals (300 linear feet; 5,100 square feet)

Condition: Very Good - The Liquid Boot is well bonded to 99 percent of the steel flume. No leakage is evident. After being drained for several days, 3 to 6 inches of standing water is still in much of the flume. Several blisters (50+) have developed in the Liquid Boot, directly over the old tar material in the seams between the flume's 3-foot-wide steel panels. Most of the blisters are in the bottom of the invert, except for a few located 1 to 2 feet up the side. The blisters typically measure 6 inches across, with the largest measuring 6 inches across by 12 inches long. The blisters are full of sand and sediment. Apparently, the Liquid Boot is poorly bonded to the old tar material, and the Liquid Boot deforms and blisters under the force of the flowing water. Once a small hole develops in the blister, the flowing water deposits sand and debris, causing the blister to grow in size. The water released from the Liquid Boot emulsion during construction probably contributed to the poor bond in the invert. Also, the blisters are more prevalent in the upstream, shaded end of the flume. During construction, the cooler temperatures in the shaded areas might have retarded cure and weakened the bond. No cutoff trench or geotextile was used on this test section.

After this test section, the Liquid Boot manufacturer (LBI) made several modifications to the construction process. A light tack coat of the "A" component improves the bond of the Liquid Boot. Also, bond in the invert can be improved by coating the sidewalls first, then coating the invert after the water released from the Liquid Boot on the sidewalls has evaporated.

Maintenance: Minor maintenance is required at this time. The District needs to cut open the blisters, trim away any unbonded material, then patch with Liquid Boot Trowel Grade. The district has been using a single-part roofing tar for minor repairs, which they report is much easier to use than the 2-part Liquid Boot Trowel Grade with equivalent performance.

Photographs: 127 and 128

Tumalo Irrigation District - Test Section T-3
Liquid Boot over a Broomed Steel Flume

Photograph 127.—Flume overview - Very good condition after 4 years of service.

Photograph 128.—Closeup of 6-inch blister on the sidewall.

Lugert-Altus Irrigation District

Test Section L-1.—

Material: Exposed Teranap geomembrane

Description: Teranap is an elastomeric bitumen geomembrane, combining Styrene-Butadiene-Styrene (SBS) polymer and asphalt with a polyester reinforcement. Teranap is available in two thicknesses: 120-mil Teranap 331 and 160-mil Teranap 431.

Construction Cost: $ 1.53 per square foot (160 mil)
$ 1.36 per square foot (120 mil)

Date Installed: May 1994 (5 years old)

Location: West Canal - Lugert-Altus Irrigation District (2,400 linear feet; 70,000 sq ft)

Condition: Very Good - After 5 years of service, the Teranap is in very good condition. The Teranap shows some surface alligator cracking but is still quite flexible. The seams are well bonded, and small areas of standing water indicate that the seepage rate is essentially zero (less than 0.1 foot per day). Little to no sediment has collected in this test section. Deer go into the canal but have not caused any damage.

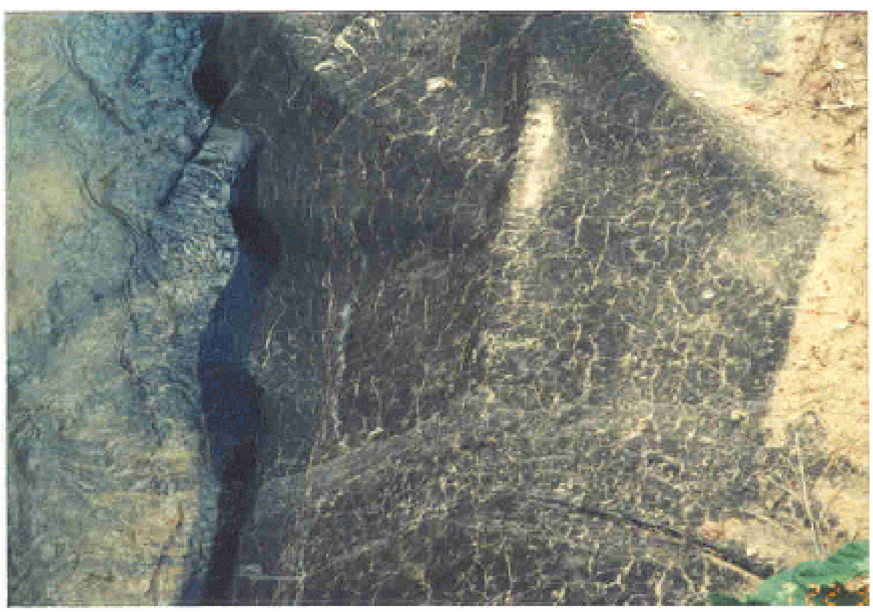
In September 1996, a large storm deposited 4½ inches of rain in about 1 hour. Surface runoff from the north and west flowed into a small drainage ditch that crosses the canal over the siphon at the upstream end of the test section. The surface runoff exceeded the capacity of the drainage ditch and flooded into the canal. The runoff washed away the berm cover and anchor stakes on the west canal bank, ran under the liner, and washedout about 300 feet of the Teranap on the west bank. The Teranap tore in several places (mostly along seams) and was deposited in the canal invert. The irrigation district reshaped the exposed subgrade and used a backhoe to pull the Teranap back into position. The district then resecured the liner with rebar driven through the liner and repaired the tears with a propane torch and additional Teranap where needed. The district raised the berm to prevent future washouts and enlarged the drainage ditch to increase capacity.

Maintenance: Irrigation district repaired the Teranap after the washout. No maintenance or problems since that time.

Photographs: 129 and 130

Lugert-Altus Irrigation District - Test Section L-1
Exposed 160-mil Teranap Geomembrane

Photograph 129.—Canal overview - Very good condition after 5 years of service. (Photograph courtesy of Lugert-Altus Irrigation District).



Photograph 130.—After 5 years, the Teranap shows some surface cracking (alligator cracking), which is normal for this product. (Photograph courtesy of Lugert-Altus Irrigation District).

Juniper Flat District Improvement Company

Test Section J-1.—

Material: Exposed 160-mil Teranap geomembrane

Description: Teranap is an elastomeric bitumen geomembrane, combining SBS (Styrene-Butadiene-Styrene) polymer and asphalt with a polyester reinforcement.

Construction Cost: $1.53 per square foot

Date Installed: October 1997 (1½ years old)

Location: Juniper Flat District Improvement Company
(975 linear feet; 26,000 square feet)

Condition: Very Good - After 1½ years of service, the Teranap is in very good condition. The Teranap shows only slight surface alligator cracking and is still quite flexible. The subgrade is quite rough, with lots of sharp subgrade rocks and roots. Little to no sediment has collected in the invert.

The seams are mostly well bonded; however, several seams (about six) were found that needed repair. Most of these unbonded seams were only 6 to 12 inches long. The largest unbonded seam was about 2 feet long and was located about 150 feet from the downstream cutoff trench.

Around the Walters Turnout, Hilte nails were used to attach the Teranap to the concrete turnout. The Hilte nails are performing well.

Maintenance: Minor - Need to reseal several seams with a propane torch.

Photographs: 131 through 136

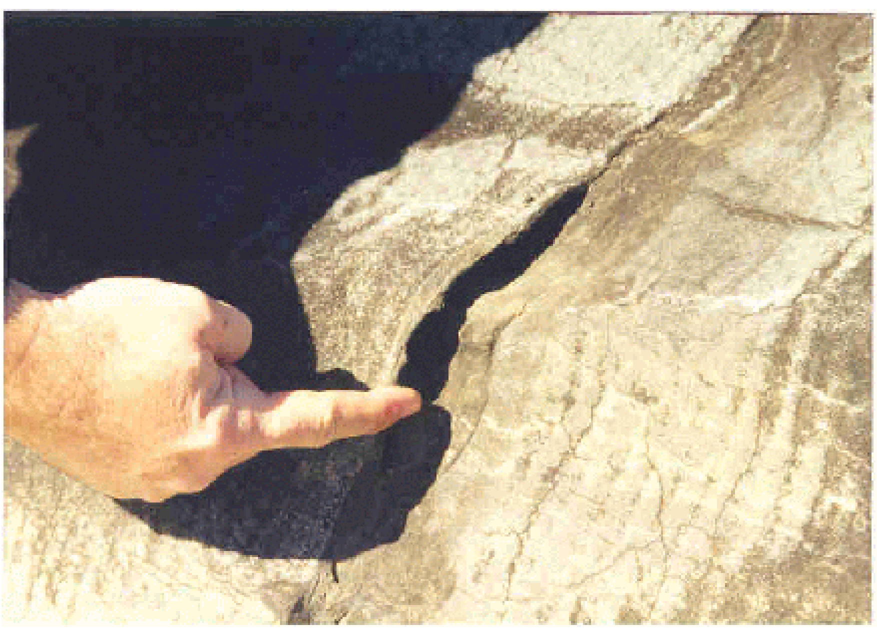
Juniper Flat Irrigation District - Test Section J-1
Exposed 160-mil Teranap Geomembrane

Photograph 131.—Canal overview - Very good condition after 1½ years of service.

Photograph 132.—Downstream cutoff trench is washing out.
Needs to be buried deeper or cover with 3-inch concrete cap.

Juniper Flat Irrigation District - Test Section J-1
Exposed 160-mil Teranap Geomembrane

Photograph 133.—Largest unbonded seam measures about 2 feet long.



Photograph 134.—Smaller unbonded seam measures about 6 inches long.

Juniper Flat Irrigation District - Test Section J-1
Exposed 160-mil Teranap Geomembrane

Photograph 135.—Hilte nails and anchor bolts used to attach Teranap to concrete turnout.

Photograph 136.—Small tear in Teranap over corner of concrete wingwall at the turnout.

CHAPTER 4
SEEPAGE ANALYSIS

The primary purpose of all the canal lining alternatives is to conserve water by reducing seepage. Full-scale ponding tests were performed at preconstruction and postconstruction to determine the effectiveness of each test section. To date, most of the ponding tests have been performed on the Arnold and North Unit test sections, and the results are summarized in tables 10 and 11.

Preconstruction Ponding Tests

The preconstruction seepage rate for the Arnold test sections ranged from 0.64 to 1.4 feet per day (ft/day), and averaged 1.0 ft/day. This value agrees with theoretical values based on the soil type and geology (USBR, May 1994). The measured preconstruction seepage rate for the North Unit test sections ranges from 2 to 20 ft/day. These values are considered high and not representative. The average seepage rate for the North Unit test sections is believed also to be about 1.0 ft/day for the following reasons:

1. Inflow-Outflow data from the 26-mile North Unit Main Canal shows an average seepage rate of about 1.0 ft/day with a conveyance loss of about 30 percent. An average seepage rate of 3 to 5 ft/day would mean that all the water would be lost to seepage, and none would be delivered. This is not the case.

2. Pond 1 was chosen as an area of known high seepage. This area was known to lose water at a high rate from visual observations of whirlpools during canal filling. Therefore, the measured seepage rate of 20 ft/day applies only to pond 1.

3. Electromagnetic investigations by the U.S. Bureau of Mines identified test sections N1 through N-4 as areas of high seepage, with test section N–3 believed to be the area of highest seepage (Ackman 1997). Ponding tests performed in 1995 and 1996 showed seepage rates of 2 to 6 ft/day with test sections N-1 and N-2 having the highest seepage. Therefore, the measured seepage rates for test sections N-1 through N-4 are not considered representative of the entire canal.

Postconstruction Ponding Tests

Arnold Ponding Tests

The Arnold test sections were constructed in 1992, and ponding tests were performed in 1991 (preconstruction), 1993 (1-year postconstruction), 1997 (5-year postconstruction), and 1998 (6-year postconstruction). The results from these ponding tests are summarized in table 7. The 1997 ponding tests used concrete dikes that were poorly anchored to the canal invert, and large amounts of leakage under the dikes caused large uncertainties in the test results. Therefore, the 1997 results are shown as a range in table 7 and 8, and some of the ponding tests were repeated in 1998 with earthen dikes.

Table 10.—Arnold Canal Ponding Tests Showing Seepage Rates and Percent Effectiveness

<table>
<tr><th>Type of Liner
and
Estimated
Percent
Effectiveness</th><th>Test*
section</th><th>Precon-
struction
1991
(ft^3/ft^2-day)</th><th>Postcon-
struction
1 year
1993
(ft^3/ft^2-day)</th><th>Postcon-
struction
5 years
1997
(ft^3/ft^2-day)</th><th>Postcon-
struction
6 years
1998
(ft^3/ft^2-day)</th></tr>
<tr><td rowspan="2">Geomembrane with
shotcrete
cover

95%</td><td>A!1</td><td rowspan="3">1.40</td><td>0.05
95%</td><td rowspan="2">0!0.3
70 - 100%</td><td rowspan="3"></td></tr>
<tr><td>A!2</td><td>0.11
89%</td></tr>
<tr><td rowspan="4">Exposed
Geomembrane

90%</td><td>A!3</td><td>-0-
100%</td><td>0 !0.1
90 - 100%</td></tr>
<tr><td>A!4</td><td rowspan="3"></td><td>-0-
100%</td><td>0.1!0.2
80 - 90%</td><td rowspan="3">0.04

96%</td></tr>
<tr><td>A!5</td><td>0.01
99%</td><td rowspan="2">0 - 0.5

50 - 100%</td></tr>
<tr><td>A!6</td><td>0.12
88%</td></tr>
<tr><td>Geomembrane with
grout mattress cover
95%</td><td>A!7</td><td rowspan="4">0.64</td><td>0.10
90%</td><td>0!0.4
60 - 100%</td><td>0.05
95%</td></tr>
<tr><td>Grout mattress

70%</td><td>A!8</td><td>0.02
98%</td><td>0.3!0.5
50 - 80%</td><td>0.29
71%</td></tr>
<tr><td></td><td>A!9</td><td>0.07
93%</td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td></td><td>A!10</td><td>0.07
93%</td></tr>
</table>

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

Table 11.— North Unit Canal Ponding Tests Showing Seepage Rates and Percent Effectiveness

Type of Liner and Estimated Percent Effectiveness	Test* section	Precon-struction 1991 (ft^3/ft^2-day)	Precon-struction 1996 (ft^3/ft^2-day)	Postcon-struction 1994 (ft^3/ft^2-day)	Postcon-struction 1998 (ft^3/ft^2-day)
	Pond 1		20.45		3.18 84% @ 1 yr.
RCC Invert Only	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.

North Unit Ponding Test

The original eight North Unit test sections (N-1 thru N-4, and N-6 thru N-9) were all constructed in 1992. However, test sections N-1 through N-4 failed in the first couple of years and were torn out and replaced with RCC in the invert (1997) with shotcrete side slopes (1998). Therefore, ponding tests for test sections N-1 through N-5 represent the following: 1991 (preconstruction), 1996 (preconstruction), 1998 (1-year postconstruction RCC invert only). The location of the ponding tests are shown in figure 6.

Test sections N-6 through N-9 still contain the original shotcrete invert and side slopes constructed in 1992, and these ponding tests represent the following: 1991 (preconstruction), 1994 (2-year postconstruction), and 1998 (6-year postconstruction).

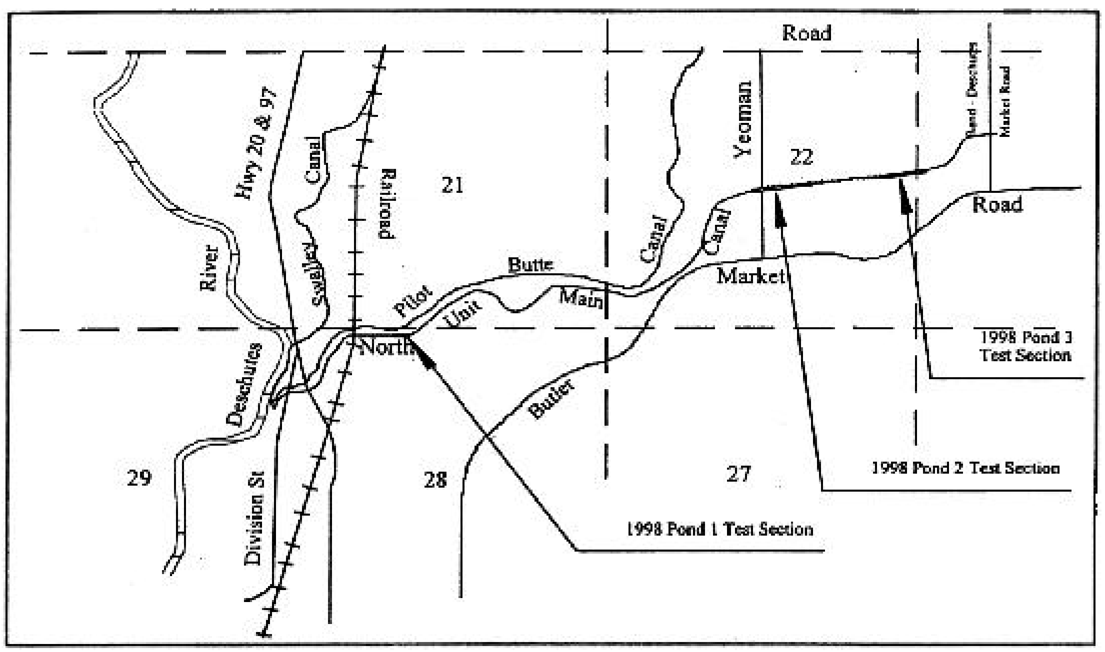


Figure 6.—General Location Map for North Unit Main Canal 1998 Ponding Tests.

Effectiveness

The various test sections have been divided into four broad categories. Linings within each of these categories use similar materials, 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. The durability and maintenance requirements were estimated based on actual 7-year performance and our knowledge of the materials. These values are only estimates , but seem like reasonable approximations and will be revisited in the year 10 report.

Table 12.—Effectiveness and Durability of Canal Linings.

Type of Lining	Number of Test Sections	Effectiveness (Seepage Reduction)	Durability
Concrete	6	70 %	40 - 60 years
Exposed Geomembrane	8	90 %	20 - 40 years
Fluid-applied Geomembrane	7	90 %	10 - 20 years
Concrete with Geomembrane Underliner	3	95 %	40 - 60 years

Concrete.—Includes RCC, Shotcrete, and grout-filled mattress. 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 (day vs. night, summer vs. 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 are routinely found where original shotcrete thickness was less than 1 inch. The grout-filled mattress has also cracked, especially in areas where the less than 1 inch thick because of the rocky subgrade conditions. Cracks tend to grow in length and numbers over the years, but so far have not widened significantly. Also the concrete degrades due to freeze thaw. All these degradation modes lead to a predicted service life of 40 to 60 years. Ponding tests on A-8, and N-6 through N-9 show an effectiveness at reducing seepage 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.

Exposed Geomembrane.—Includes HDPE, Hypalon, Teranap, and PVC with geotextile cover. Geomembranes are quite watertight when new, but continued effectiveness depends on both chemical and mechanical resistance. Effectiveness is estimated at 90% based on the ponding tests on test sections A-3, A-4, A-5,and A-6. This value is slightly lower than geomembrane with concrete cover because of the potential for mechanical damage (animal traffic, equipment damage, and vandalism). Design life is predicted at 20 to 40 years again because of the potential for mechanical damage. The design life varies slightly depending of the UV resistance and thickness of the geomembrane. Exposed geomembranes will require more maintenance than concrete lining because of mechanical and UV damage.

Fluid-applied Geomembrane .—Another type of exposed geomembrane where the geomembrane is actually fabricated onsite. Maintenance requirements will be the same as for an exposed geomembrane. However the anticipated durability is lower (10 to 20 years) because of problems with field manufacturing (difficult to control quality, thickness and physical properties because of the weather).

Concrete with Geomembrane underliner.—Concrete includes RCC, shotcrete, and grout-filled mattress. Geomembrane underliner includes all types of geomembranes such as PE geocomposite, HDPE, VLDPE, and PVC. Concrete will crack and degrade; however, the system will remain watertight because the geomembrane is the water barrier, and the concrete only acts as a protective cover. Therefore small cracks and defects in the concrete cover do not effect the system effectiveness. Ponding tests on Test Sections A-1, A-2, and A-7 show effectiveness of about 95%. Maintenance requirements same as concrete alone or (perhaps slightly less because of more uniform thickness). Durability should be the same as concrete alone (40 to 60 years).

Ponding Test - North Unit Main Canal
Shotcrete Test Sections

Photograph 137.—Dike for ponding test at station 28+00.

Photograph 138.—Concrete dike is 4 inches thick.

Tumalo Irrigation District - Seepage Rates

Ponding tests have not been performed on the Tumalo test sections. Since the flumes are above ground, the seepage estimates are based on visual indications.

Test section T-1 - is a concrete flume immediately downstream from the diversion dam on the Deschutes River. Before lining with Liquid Boot, this flume leaked significantly through the deteriorated concrete sidewalls. Water leaking from the flume returned to the nearby Deschutes River was not a major concern. Preconstruction seepage was estimated at about 1,000 gallons per minute (gpm), which is equivalent to about 150 ft/day (based on a length of 75 feet and a wetted perimeter of 19 feet). The short-term postconstruction seepage rate was estimated at about 200 gpm, or about 30 ft/day. However, the Liquid Boot was poorly bonded to the existing concrete, and degraded quickly. This test section has been replaced with buried pipe.

Test section T-2 - Flume Number 4 is a 463-ft-long elevated steel flume on the Bend Feed Canal. The flume is built on a wooden trestle that crosses a small stream and valley. Before lining with Liquid Boot, this flume leaked significantly at the seams between the 3-ft metal panels. Also, the metal itself was starting to corrode and had pinholes which were contributing to the seepage. The irrigation district routinely shoveled small quantities of clay into the flume to reduce the seepage. Any water leaking from the flume eventually ends up in the small stream in the valley below. District personnel estimated the seepage at 0.5 cfs (200 gpm), which is equivalent to 8.5 ft/day (based on a length of 463 feet and a wetted perimeter of 11 feet). The postconstruction seepage rate is estimated at essentially zero, with no visible seepage.

Test section T-3 - (Klippel Flume) is a 267-ft-long steel flume. The flume is built on a wooden trestle that crosses a small stream and valley. The Klippel flume carries the combined flows of the Bend and Tumalo Feed Canals. Before lining with Liquid Boot, this flume leaked significantly at the seams between the 3-ft metal panels. Also the metal itself was starting to corrode and had pinholes which were contributing to the seepage. The irrigation district routinely shoveled small quantities of clay into the flume to reduce the seepage. Water leaking from the flume would eventually end up in the small stream in the valley below. District personnel estimated the seepage at 0.5 cfs (200 gpm), which is equivalent to 15 ft/day (based on a length of 267 feet and a wetted perimeter of 11 feet). The postconstruction seepage rate is estimated at essentially zero, with no visible seepage.

The estimates for Test Section T-1 are quite crude, since it is difficult to visually estimate how much water is flowing out of the concrete flume and back into the river. The estimates for Test sections T-2 and T-3 are more accurate, since the district can visually see the amount of water leaking out of the elevated steel flumes.

Lugert-Altus Irrigation District (West Canal) - Seepage Rates

Test section L-1 - The West Canal generally flows 70 to 80 days of the year. Earlier studies (Bureau of Reclamation, September 1985; ECS Technical Services, July 1985) performed ponding tests over a 750-ft section and calculated a preconstruction seepage rate for the West Canal at 0.4 ft/day. District personnel believe the seepage rate in the area of this test section is significantly higher, because 30+ acres of adjacent farmland has been unusable because of seepage from the canal. Before lining, the irrigation district estimates that 1 to 2 acre-feet of water per day were lost to seepage over this 2,400-ft reach of canal. Based on a wetted perimeter of 23 feet, this equates to a seepage rate of 0.8 to 1.6 ft/day.

The irrigation district believes that the postconstruction seepage rate is essentially zero over the ½-mile test section because, the year following installation of the test section, the 30 acres of land adjacent to the canal were returned to production for the first time in over a decade.

CHAPTER 5
BENEFIT/COST ANALYSIS

All the canal-lining alternatives are compared using Benefit/Cost (B/C) analysis. Alternatives with a B/C ratio greater than 1 are economically viable, while 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. Secondary benefits are also achieved by canal lining, such as use of adjacent cropland normally flooded by leaking canals and remediation of damage to structures near canals (such as flooded basements). 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 ft/day (ft^3/ft^2-day). The effectiveness, durability, and maintenance requirements for the 4 generic types of canal-lining are listed in table 13.

Table 13.—Comparison of Generic Types of Canal Lining

Type of lining	Number of test sections	Effectiveness (seepage reduction) (percent)	Durability (years)	Maintenance ($/$ft^2$-yr)
Concrete	6	70%	40 - 60	0.005
Exposed geomembrane	8	90%	20 - 40	0.010
Fluid-applied geomembrane	7	90%	10 - 20	0.010
Concrete with geomembrane underliner	3	95%	40 - 60	0.005

Cost - The cost of each alternative is calculated as its life-cycle cost ($/$ft^2$-yr). Life-cycle costs are calculated using initial costs, design life (durability), and maintenance costs. Initial costs were taken from tables 2 and 3 in chapter 1 of this report. Durability (years) and maintenance costs were taken from table 13 above.

Benefit/Cost Ratios - B/C ratios were calculated for each test section and are tabulated in table 14. Sample calculation is shown in appendix B-1. Many test sections have favorable B/C ratios, and the lining alternatives with the highest B/C ratio include exposed geomembranes, geomembranes with concrete cover, and concrete alone. Each of these alternatives has advantages and disadvantages, and is discussed in further detail below. In addition, a couple of suboptions are discussed such the B/C of the geomembrane underliner component and the B/C of performing annual maintenance.

Exposed Geomembrane - Includes HDPE, Hypalon, and Teranap. These exposed geomembranes have favorable B/C ratios in the range of 3.0 to 3.9. They are relatively easy to construct and can be installed by irrigation districts with their own equipment and labor. They can be installed without significant overexcavation and with minimal loss of freeboard. The biggest disadvantage is the risk of mechanical damage (animal traffic, maintenance equipment, vandalism, etc.), as well as environmental damage from UV light. Also, exposed geomembranes can have uplift problems if not ballasted in the invert. High velocities seem to compound uplift problems. Finally, exposed geomembranes are often poorly maintained because of the district's lack of experience with these materials and the special equipment sometimes needed for repairs (such as an extrusion welder for HDPE and PP). Exposed geomembranes show promise for some special applications such as lining of existing steel flumes.

Concrete Alone - includes RCC with shotcrete side slopes, shotcrete alone, and grout-filled mattress. These concrete liners have favorable B/C ratios ranging from 3.0 to 3.2. Concrete provides a hard durable surface that is resistant to mechanical damage. District personnel are familiar with concrete and can easily perform the required maintenance. The only disadvantage is that concrete develops cracks over time, reducing long-term effectiveness to about 70 percent.

Geomembrane With Concrete Cover - Includes a variety of geomembranes and concrete covers including shotcrete over PE, shotcrete over PVC, and grout-filled mattress over PVC. These lining alternatives have favorable B/C ratios ranging from 3.5 to 3.7. These linings offer the highest effectiveness (95 percent) because the geomembrane provides the water barrier, while the concrete protects the geomembrane from mechanical damage and weathering. Maintenance requirements are virtually identical to concrete alone.

Spray-Applied Geomembranes - Includes sprayed-in-place foam, coated geotextile, and Liquid Boot over existing concrete. These spray-applied membranes have unfavorable B/C ratios ranging from 0.2 to 0.5. Problems with field fabrication of these spray-applied membranes make them a poor choice, except perhaps for special applications such as lining of existing steel flumes as discussed below.

Geomembrane Lining of Steel Flumes - Includes Liquid Boot and PP. These lining alternatives for existing steel flumes have favorable B/C ratios ranging from 1.8 to 2.7. The PP alternative is an exposed geomembrane and may be difficult to maintain because of the need for an extrusion welder for patching. The Liquid Boot is the only spray-applied membrane that is still in service, and shows that steel flumes may be a specialty application for this type of product. Surface preparation by sandblasting of the steel flume has not proven cost effective, because the expensive sandblasting did not improve performance over brooming.

Geomembrane Underliner - B/C analysis allows for the evaluation of some of the individual components of a lining alternative. The addition of the geomembrane underliner to a concrete liner has a favorable B/C ratio of about 4.8, showing that the small additional one-time cost of the geomembrane yields big benefits by raising the effectiveness from 70 percent up to 95 percent.

Table 14.—Benefit-Cost Analysis

Test Section	Construction Cost ($\$/ft^2$)	Durability (years)		Annualized* Construction Cost ($\$/ft^2$-yr)	Maintenance Cost ($\$/ft^2$-yr)	Total Cost ($\$/ft^2$-yr)	Effectiveness Seepage Reduction (%)	Benefit / Cost	
		Range	Average					Range	Average
A-1	2.43	40-60	50	0.049	0.005	0.054	95	3.0 - 4.3	3.7
A-2	2.52	40-60	50	0.050	0.005	0.055	95	2.9 - 4.2	3.5
A-3	1.38	20-40	30	0.046	0.010	0.056	90	2.4 - 4.2	3.3
A-4	1.05	10-20	15	0.070	0.010	0.080	90	1.6 - 3.0	2.3
A-5	1.11	20-40	30	0.037	0.010	0.047	90	2.8 - 4.9	3.9
A-6	1.03	15-35	25	0.041	0.010	0.051	90	2.4 - 4.7	3.6
A-7	2.54	40-60	50	0.051	0.005	0.056	95	2.9 - 4.1	3.5
A-8	1.92	40-60	50	0.038	0.005	0.043	70	2.7 - 3.9	3.3
A-9 and 10	1.79	Removed from Study at District's Request - No Analysis							
N-1	4.33	5-15	10	0.433	0.010	0.443	40	0.1 - 0.3	0.2
N-2	3.92	5-15	10	0.392	0.010	0.402	40	0.1 - 0.2	0.2
N-3 and 4	2.64	1-5	3	0.880	0.010	0.890	90	0.0 - 0.2	0.2
RCC Invert	1.74	40-60	50	0.035	0.005	0.040	40	1.7 - 2.4	2.1
N-5	2.00	40-60	50	0.040	0.005	0.045	70	2.6 - 3.8	3.2
N-6	2.20	40-60	50	0.044	0.005	0.049	70	2.4 - 3.5	3.0
N-7 and 8	2.14	40-60	50	0.043	0.005	0.048	70	2.5 - 3.6	3.0
N-9	2.07	40-60	50	0.041	0.005	0.046	70	2.5 - 3.7	3.1
T-1	1.45	5-15	10	0.145	0.010	0.155	40	0.3 - 0.8	0.5
T-2	2.16	10-20	15	0.144	0.010	0.154	90	0.8 - 1.6	1.2
T-3	1.40	10-20	15	0.093	0.010	0.103	90	1.2 - 2.3	1.8
L1 and J1	1.53	20-40	30	0.051	0.010	0.061	90	2.1 - 3.9	3.0
O-1	0.85	New Test Section - No Analysis							
O-2	0.79	New Test Section - No Analysis							
F-1	0.90	New Test Section - No Analysis							
Underliner	0.54	40-60	50	0.011	0.000	0.011	25	3.8 - 5.7	4.8
Maintenance									
Concrete + Geomembrane	0	40-60	50	0.000	0.005	0.005	47.5	19.6	19.6
Concrete alone	0	40-60	50	0.000	0.005	0.005	35	14.5	14.5
Exposed Geomembrane	0	40-60	50	0.000	0.010	0.010	45	9.3	9.3
Fluid-applied membrane	0	40-60	50	0.000	0.010	0.010	45	9.3	9.3

*Annualized Construction Costs calculated at zero percent interest.

Maintenance - During the 7-year period, the maintenance requirements of all the alternatives have been quite low ($0.005 to $0.010 per sq ft per year). However, annual maintenance is believed to have a large effect on the durability and effectiveness. For this analysis, annual maintenance is estimated to double the design life of all the alternatives (an equivalent B/C analysis is that annual maintenance doubles the effectiveness of each alternative over a fixed design life). Benefit/Cost analysis shows that annual maintenance on all the alternatives has a very favorable B/C ratio, ranging from 10 to 20. This means that every dollar spent on maintenance returns $10 to $20 in conserved water.

Sensitivity Analysis - The B/C ratios are estimates based on numerous assumptions and input parameters. The B/C ratios are directly proportional to the value of conserved water, effectiveness, durability, and preconstruction seepage rates, while inversely proportional to construction costs. Therefore, changes to these parameters would cause proportional changes in all the alternatives and would not change the relative position of the alternatives. Maintenance costs have been low for all the alternatives and, therefore, have minimal effect. To illustrate, table 15 summaries B/C ratios for all the alternatives based on water values of $25, $50, and $75 per acre-foot.

Table 15.—Sensitivity of Benefit-Cost Analysis to Value of Conserved Water

Lining type	Test section	Description	Benefit/Cost per value of conserved water ($ per acre-ft)		
			$25	$50	$75
Geomembrane with concrete cover	A-1	4-mil PE with shotcrete cover	1.8	3.7	5.5
	A-2	30-mil PVC with shotcrete cover	1.8	3.5	5.3
	A-7	40-mil PVC with grout mattress	1.8	3.5	5.3
Concrete	A-8	Grout-filled mattress	1.7	3.3	5.0
	N-5	RCC Invert with shotcrete side slopes	1.6	3.2	4.8
	N-6	Shotcrete with steel fibers	1.5	3.0	4.4
	N-7	Shotcrete with polyfibers	1.5	3.0	4.5
	N-8	Shotcrete with polyfibers	1.5	3.0	4.5
	N-9	Unreinforced shotcrete	1.6	3.1	4.7
Exposed geomembrane	A-3	80-mil HDPE	1.7	3.3	5.0
	A-4	30-mil PVC with geotextile UV cover	1.2	2.3	3.5
	A-5	45-mil Hypalon with Geotextile Cushion	2.0	4.0	5.9
	A-6	36-mil Hypalon with geotextile cushion	1.8	3.6	5.4
	T-3	Liquid Boot over steel flume	0.9	1.8	2.7
	L-1	45-mil polypropylene over steel flume	1.5	3.0	4.6

CHAPTER 6
CONCLUSIONS

1. Three types of canal linings (concrete, exposed geomembrane, and concrete with geomembrane underliner) showed favorable B/C ratios in the range of 3.0 to 3.9.

Type of Lining	Construction Cost ($/ft2)	Durability (years)	Maintenance Cost ($/ft2-yr)	Effectiveness at Seepage Reduction (percent)	B/C Ratio
Fluid-applied Membrane	$1.40 - $4.33	10 - 20 yrs	$0.010	90 %	0.2 - 1.8
Concrete alone	$1.92 - $2.33	40 - 60 yrs	$0.005	70 %	3.0 - 3.2
Exposed Geomembrane	$1.03 - $1.53	20 - 40 yrs	$0.010	90 %	3.0 - 3.9
Geomembrane with Concrete Cover	$2.43 - $2.54	40 - 60 yrs	$0.005	95 %	3.5 - 3.7

2. Each of these linings has advantages and disadvantages. The geomembrane with concrete cover seems to offer the best long-term performance.

   a. **Concrete** - Has excellent durability, but only 70-percent long-term effectiveness. Irrigation districts are familiar with concrete and can easily preform required maintenance.

   b. **Exposed Geomembrane** - Has excellent effectiveness (90 percent),but is susceptible to weathering as well as mechanical damage from animal traffic, construction equipment, and vandalism. Also, irrigation districts cannot easily preform maintenance, because of unfamiliarity with geomembrane materials, and the need for special seaming equipment to perform repairs.

   c. **Concrete With Geomembrane Underliner** - The geomembrane underliner provides the water barrier, while the concrete cover protects the geomembrane from mechanical damage and weathering. The system effectiveness is estimated at 95 percent. The irrigation district can readily maintain the concrete cover, but does not have to maintain the geomembrane underliner.

3. **New Test Sections** - Some of the newest test sections have not been in service very long, and the authors are hesitant to draw too many conclusions. These test sections include Exposed PP over an existing steel flume (test section F-1), exposed GCL (test section O-1), and buried GCL (test section O-2). While these test sections look very promising, more time is needed to evaluate.

4. **Lining Alternatives for Existing Steel Flumes** - two viable alternatives were identified.

   a. **Exposed Polypropylene (PP)** - Excellent effectiveness (90 percent). Installed for less than a year, but looks promising. Only drawback is need for extrusion welder to perform maintenance repairs. Other exposed geomembranes (such as HDPE and Hypalon) would also work for this application.

b. **Liquid Boot -** Excellent effectiveness (90 percent). Problems with blistering below the waterline raise questions about durability. Can be repaired with hand-mix version.

5. **Maintenance -** Through 7 years, maintenance costs have been relatively low for all the lining alternatives. Generally, exposed geomembranes require about twice the maintenance of concrete linings (\$0.010 versus \$0.005/ft^2/yr). For all lining alternatives, B/C analysis shows that every \$1 spent on maintenance returns \$10 to \$20 in conserved water by increasing effectiveness and design life. Therefore, more emphasis should be placed on maintenance.

CHAPTER 7
FUTURE STUDIES

Additional Test Sections - Reclamation is collaborating with manufacturers to install an exposed EPDM test section and on exposed LLDPE on the Ochoco Irrigation District. EPDM and LLDPE have excellent UV resistance and are quite resistant to mechanical damage because of their toughness and flexibility. Installation of these test sections is planned for fall 1999. The details of these test sections will be covered in the "2000 Supplemental Report."

Seepage Studies - Ponding tests are planned on the North Unit test section for Fall 1999 to determine the postconstruction seepage rate of the shotcrete (test sections N-6, N-7, N-8, and N-9) and of the RCC invert with shotcrete side slope (test section N-5). These ponding tests will also be covered in the "2000 Supplemental Report." Additional ponding tests are planned on the North Unit and Arnold Test Sections after Year 10 to determine long-term seepage rates.

Repairs - The irrigation districts do not have the equipment or expertise to perform repairs on the exposed geomembrane test sections. Reclamation previously purchased a hand-held thermal tack welder to assist with these repairs. However, the tack welder did not prove acceptable. Reclamation is now considering the purchase of a small extrusion welder for field repairs of HDPE and PP geomembranes. If acceptable, the extrusion welder will be loaned out to irrigation districts as needed.

Final Report - The final report is scheduled for publication in 2002 (Year 10) and will provide long-term data on the design life, maintenance costs, life-cycle costs, long-term seepage rates (effectiveness), cost of conserved water, and B/C analysis for each test section.

Appendix A-1

Material Data Sheets (NOT INCLUDED)

Juniper Flat Irrigation District

Appendix A-2

Material Data Sheets (NOT INCLUDED)

Ochoco Irrigation District

Appendix A-3

Material Data Sheets (NOT INCLUDED)

Frenchtown Irrigation District

Appendix B-1

Example Calculation of

Benefit/Cost Ratios

Benefit/Cost Ratio = B/C

Benefit = B = E * S * I * V ($/ft^2-yr)

Cost = C = (K / D) + M ($/ft^2-yr)

where	E	=	Effectiveness (%)
	S	=	Seepage rate = 1.0 ft/day = 1.0 ft^3/ft^2-day
	I	=	Irrigation Season 180 days/year
	V	=	Value of Water = $50/acre-ft (acre-ft = 43,560 ft^3)
	K	=	Construction Cost ($/ft^2)
	D	=	Durability (years)
	M	=	Maintenance Cost ($/ft^2-yr)

For Test Section A-1

E	=	Effectiveness = 95%
S	=	Seepage Rate = 1.0 ft^3/ft^2-day
I	=	irrigation Season = 180 days per year
V	=	Value of Water = $50/acre-ft
Acre-ft	=	43,560 ft^3
K	=	Construction Cost = $2.43/ft^2
D	=	Durability = 50 years
M	=	Maintenance Cost = $0.005/ft^2-yr

Benefit = E * S * I * V = 0.95 * 1.0 * 180 * 50 / 43,560 = 0.196 ($/ft^2-yr)

Cost = (K / D) + M = (2.43 / 50) + 0.005 = 0.0536 ($/ft^2-yr)

B/C = 0.196 / 0.0536

<u>B/C = 3.66</u> per table 14

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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.