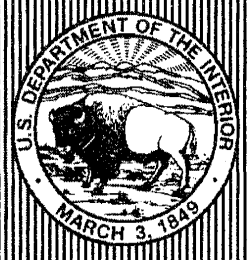
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CANAL-LINING DEMONSTRATION PROJECT
YEAR 10 FINAL REPORT

November 2002

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 34 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 test sections after 1 to 10 years of service. This report also documents the construction of five of the newest tests sections .

At this time, seven of the test sections have failed, while the remaining test sections are in fair to excellent conditions. Each test section covers about 30,000 square feet, and unit construction costs ranged from less than $1.00 to more than $4.00 per ft^2. The test sections are divided into four generic types: exposed geomembranes, fluid-applied membranes, geomembranes with concrete cover, and concrete alone. Preconstruction and postconstruction ponding test have shown effectiveness at reducing seepage between 70 and 95 percent. The most promising lining alternative demonstrate benefit/cost ratios between 3 and 4.

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by

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Pacific Northwest Region
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Boise, Idaho

November 2002

Mission Statements

U.S. Department of the Interior

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 Indian tribes and our commitments to island communities.

Bureau of Reclamation

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.

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The authors wish to thank the irrigation districts whose support was essential to the planning and implementation of this project. Reclamation particularly appreciates the support from the boards of directors of the Arnold, North Unit, Tumalo, Ochoco, Juniper Flat, Frenchtown, Lugert-Altus, Bitter Root, Buffalo Rapids, and Lewiston Orchards Irrigation Districts. Reclamation also wants to thank Mr. Rick Stone, a private landowner on the Twin Falls Irrigation District, for participating in the installation of a test section on his property. Water user support consisted of both a financial commitment and the acceptance of the risks involved with using unfamiliar technologies.

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GLOSSARY

CSPE	=	Chlorosulfanated polyethylene
CSPE-R	=	Reinforced chlorosulfanated polyethylene
EPDM	=	Ethylene Propylene Diene Monomer
EVA	=	Ethylene vinyl acetate
GCL	=	Geosynthetic clay liner
HDPE	=	High density polyethylene
LLDPE	=	Linear low density polyethylene
mPE	=	metallized polyethylene
PE	=	Polyethylene
PP	=	Polypropylene
PVC	=	Polyvinyl chloride
RCC	=	Roller compacted concrete
UV	=	Ultraviolet
VLDPE	=	Very low density polyethylene

EXECUTIVE SUMMARY

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

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

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

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

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

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

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

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

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

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

New Test Sections

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

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

Coupon Testing

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

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

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

CHAPTER 1
INTRODUCTION

Traditional canal-lining materials typically include compacted clay, reinforced or unreinforced concrete, and (more recently) buried geomembranes. However for some jobs, these materials are not always viable for the following reasons: (1) they are not locally available (such as compacted clay), (2) they are too expensive (for example, reinforced concrete), (3) they require large rights-of-way for heavy construction equipment (such as unreinforced concrete), or (4) they require extensive over-excavation and subgrade preparation (such as for buried geomembranes). This study looks at alternative canal-lining materials that are less expensive, easier to construct where access is limited, and compatible with severe rocky subgrades such as the fractured volcanic basalt typically found in the Pacific Northwest.

To date, 34 test sections have been constructed on 11 irrigation districts (five irrigation districts on the Deschutes river in central Oregon, two in Idaho, three in Montana, and one in Oklahoma). The lining materials include combinations of geosynthetics, shotcrete, roller compacted concrete, grout mattresses, soil, elastomeric coatings, and sprayed-in-place foam. The test sections now range in age from 1 to 10 years.

There are five previous reports in this series. The first report "*Deschutes - Construction Report*" (Reclamation Report R-94-06, 1994) documented the construction of the original 18 test sections over severe rocky subgrades on the Arnold and North Unit Irrigation Districts near Bend, Oregon. 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. Post-construction seepage rates were 10 to 100 times lower than preconstruction rates.

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), detailed the construction of 4 additional test sections. That report also assessed the condition of all 22 test sections after up to 5 years of service (through October 1996).

The fourth report, "Deschutes - Year 7 Durability Report" (Reclamation Report R-99-06), details the construction of five new test sections and 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.

The fifth report, "Deschutes - 2000 Supplemental Report" (Reclamation Report R-00-01), details the construction of two test sections constructed in the fall of 1999.

This sixth report details the construction of five new test sections and assesses the performance of all 34 test sections after up to 10 years of service. Tables 1, 2, 3, and 4 show the initial construction costs for all 34 test sections.

These costs should be used for comparison purposes only. Material costs are believed accurate, but should be verified with the geosynthetic manufacturers. These costs are based on a minimum job size of 100,000 to 200,000 square feet (i.e., a minimum of one full truckload of lining materials). Actual

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

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

Environmental Assessment of Canal Lining

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

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

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

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

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

Value of Conserved Water

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

Table 1.— Irrigation Districts that have participated in the Canal Lining Demonstration Project

Irrigation District	Section Identifier	Location (State)	Original Test Sections Installed 1991 & 1992	Test Sections Installed 1994	Test Sections Installed 1994 & 1995	Test Sections Installed 1997	Test Sections Installed 1998, 1999 & 2000	Test Sections Installed 2001	Test Sections Currently being Monitored
Arnold ID	A-1 thru 10	Oregon	10						8
North Unit ID	N-1 thru 9	Oregon	8				1		5
Tumalo ID	T-1 thru 3	Oregon			3				0
Ochoco ID	O-1 thru 5	Oregon					5		4
Juniper Flat Improvement Co.	J-1	Oregon				1			1
Lugert-Altus ID	LA-1	Oklahoma		1					1
Frenchtown ID	F-1	Montana					1		1
Buffalo Rapids ID	BU-1	Montana						1	1
Bitter Root ID	BI-1	Montana						1	1
Lewiston Orchards ID	LO-1	Idaho					1		1
Rick Stone Ranch	TF-1	Idaho					1		1

Note: Ten Irrigation Districts and One Individual Rancher.

Table 2.—Canal Lining Costs - Arnold and North Unit Test Sections

Section No.	Description	Lining Material				Subgrade Preparation	Installation	Overhead and profit	Total
		Geomembrane $ / ft²	Geotextile $ / ft²	Shotcrete $ / ft²	Other cost $ / ft²	$ /ft²	$ / ft²	(%)	$ / ft²
A-1	4-mil PE Geocomposite with Shotcrete cover								
	Unreinforced Shotcrete	$0.30		$0.87		$0.26	$0.65	17%	$2.43
	Polyfiber reinforced Shotcrete	$0.30		$0.87	$0.06[a]	$0.26	$0.65	17%	$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-filled mattress on side slopes only	$0.55	$0.12	$0.21	$0.16	$0.04	$0.45	17%	$1.79
Section No.	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			$1.08	$0.22	$0.04	$0.65	17%	$2.33
	25 lbs. per cubic yard			$1.08	$0.11	$0.04	$0.65	17%	$2.20
N-7 and N-8	Shotcrete polyfiber reinforced								
	3 lbs. per cubic yard			$1.08	$0.12	$0.04	$0.65	17%	$2.21
	1-1/2 lbs. per cubic yard			$1.08	$0.06	$0.04	$0.65	17%	$2.14
N-9	Unreinforced Shotcrete			$1.08		$0.04	$0.65	17%	$2.07

[a] Cost of Polyfibers

Table 3.—Canal Lining Costs - Tumalo and Ochoco Test Sections

Section No.	Description	Lining Material				Subgrade Preparation $ / ft²	Installation $ / ft²	Overhead and Profit %	Total $ / ft²
		Geomembrane $ / ft²	Geotextile $ / ft²	Shotcrete $ / ft²	Other Cost $ / ft²				
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
O-1a	Covered GCL - Bentomat DN	$0.29				$0.26	$0.15	17%	$0.82
O-1b	Covered GCL - Bentomat CL	$0.33				$0.26	$0.15	17%	$0.87
O-2a	Exposed GCL - Bentomat DN	$0.29				$0.26	$0.10	17%	$0.76
O-2b	Exposed GCL - Bentomat CL	$0.33				$0.26	$0.10	17%	$0.81
O-3a	Exposed 45-mil EPDM PondGard with 8-oz geotextile on side slopes only	$0.30	$0.06			$0.26	$0.10	17%	$0.84
O-3b	Exposed 45-mil EPDM PondGard with 8-oz geotextile on side slopes only and covered invert	$0.30	$0.06			$0.26	$0.12	17%	$0.87
O-4	Exposed 30-mil LLDPE EnviroLiner with 8-oz geotextile on side slopes only	$0.25	$0.06			$0.26	$0.10	17%	$0.78
O-5	Exposed 160-mil Coletanche	$0.93				$0.26	$0.10	17%	$1.51

Table 4.—Canal Lining Costs - Lugert-Altus, Juniper Flat, Frenchtown, Twin Falls, Lewiston, Buffalo Rapids, and Bitter Root Irrigation District Test Sections

Section No.	Description	Lining Material				Subgrade Preparation $ / ft²	Installation $ / ft²	Overhead and Profit %	Total $ / ft²
		Geomembrane $ / ft²	Geotextile $ / ft²	Shotcrete $ / ft²	Other Cost $ / ft²				
LA-1	Exposed 160-mil Teranap Exposed 120-mil Teranap	$0.95 0.80				$0.12 0.12	$0.10 0.10	17% 17%	$1.53 1.19
J-1	Exposed 160-mil Teranap	$0.95				$0.26	$0.10	17%	$1.53
F-1	Exposed 45-mil PP over a broomed steel flume	$0.40			$0.12[a]	$0.10	$0.15	17%	$0.90
TF-1	Exposed 40-mil Wet-applied Polyurethane Geocomposite over existing concrete	$0.75			$0.15[b]	$0.12	$0.20	17%	$1.43
LO-1	Exposed 45-mil Reinforced Metallocene	$0.32	$0.10		$0.07[a]	$0.26	$0.10	17%	$0.99
BU-1a	Exposed 60-mil GSE White Textured HDPE with 10-oz geotextile cushion	$0.60	$0.12			$0.26	$0.10	17%	$1.26
BU-1b	Exposed 60-mil GSE White Textured HDPE	$0.60				$0.26	$0.10	17%	$1.12
BI-1	Exposed Geocomposite (12-oz geotextile - 30-mil EVA - 16oz geotextile) (8-oz geotextile - 20-mil EVA - 8-oz geotextile)	 $0.53 0.35				 $0.26 0.26	 $0.10 0.10	 17% 17%	 $1.04 0.83

[a] Cost for fabricating panels in the plant
[b] Cost of resin freight

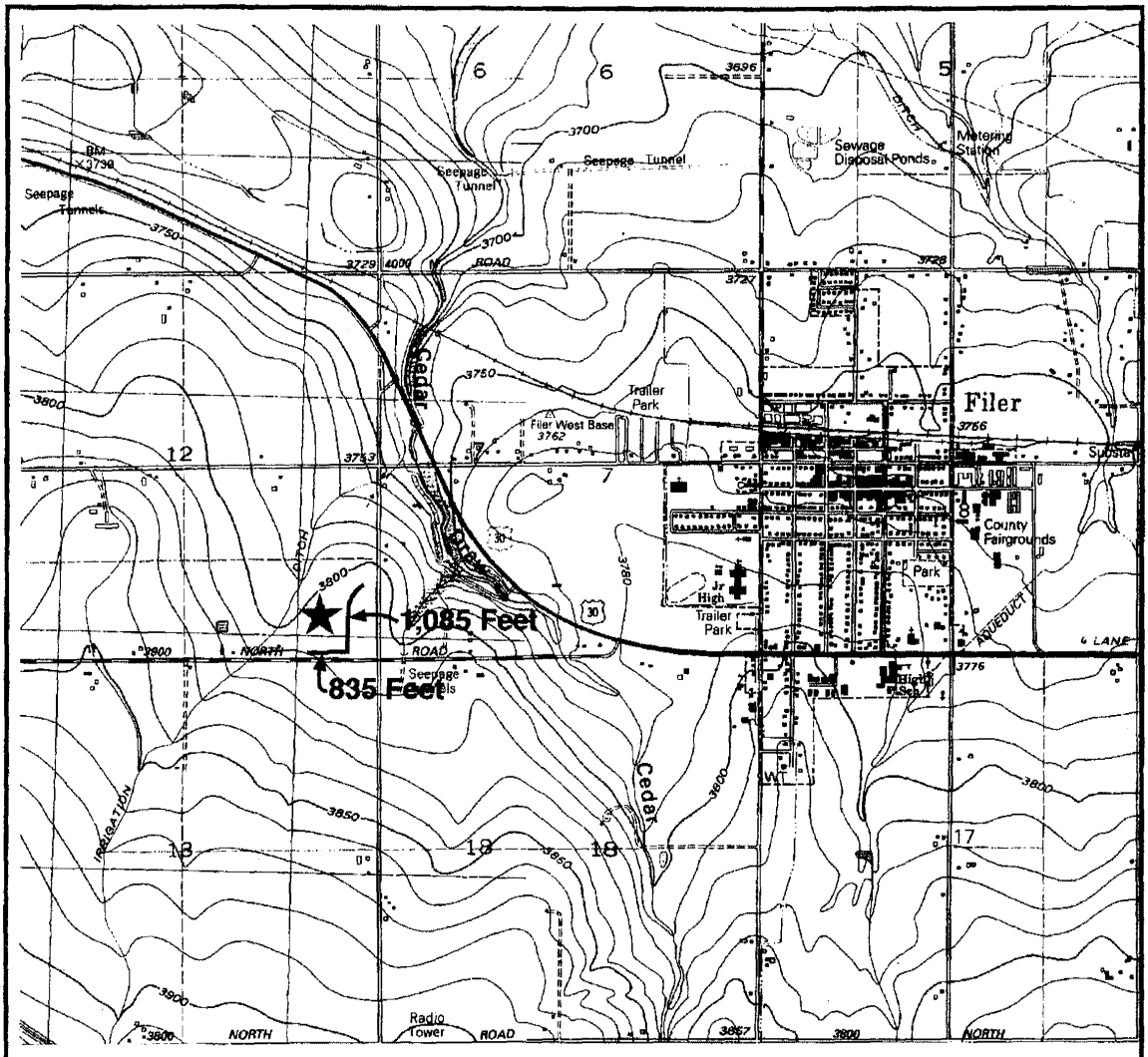
CHAPTER 2
NEW TEST SECTIONS

Five new test sections were constructed during the previous 2 years. The new test sections are:

- TF-1 Exposed, 40-mil, wet-applied polyurethane geocomposite
- LO-1 Exposed, 45-mil, reinforced metallized polyethylene
- O-5 Exposed, 160-mil, bituminous geomembrane
- BU-1 Exposed, 60-mil, white textured HDPE
- BI-1 Exposed 20-mil EVA geocomposite

Test Section TF-1.—

Material:	Exposed, 40-mil, wet-applied polyurethane geocomposite over existing concrete
Date Installed:	June 2000
Location:	Twin Falls, Idaho - about 7 miles west of town near Filer, Idaho (figure 1) (1,920 linear feet, 11,500 square feet)
Description:	Liner consists of 2 layers of 3-oz, heat-bonded, non-woven geotextile saturated with liquid polyurethane resin for a total minimum thickness of 40 mils. Geotextile is Linq Typar 3301 nonwoven, spunbonded, polypropylene geotextile (data sheet is in appendix A)
Prime Contractor:	Canal Lining Systems LLC with assistance from Ditch Line LLC
Process Developed by:	Payne Technology Companies Innovative Process Corporation (IPC)
Material Supplier:	Bayer Corporation
Surface Preparation:	The land owner was responsible for surface preparation, including digging a 6-inch deep anchor trench on each side of the concrete ditch. The land owner's two to three man crew cleaned the concrete ditch by scraping with a shovel or hoe to loosen dirt and then shoveled out all dirt and debris. This level of surface prep was similar to other IPC jobs, such as a job in Pueblo, Colorado. Canal Lining Systems personnel reviewed the work and requested additional surface preparation to aid the wet-applied polyurethane in bonding to the concrete. Therefore, a 2,000-gallon water truck was rented ($300/day), along with a high-pressure power washer ($50/day) and four additional laborers for 1½ days. After jet cleaning, the dirt and debris were flushed through the canal into the drainage ditch. Final surface preparation looked very good. There remained only minimal dirt on the sidewalls and a few areas with some dirt in the ditch invert. On the morning of liner installation, a weedburner was used to remove any puddles or moisture left in the invert. The total cost for surface preparation is estimated at $0.12 per ft^2 for a large job (a minimum of 100,000 ft^2).
Mobilization:	Mobilization costs for this liner can be significant because the lining machine weighs approximately 40,000 pounds and has to been trucked onto the site. Also, six to eight skilled workers from Canal Lining Systems LLC and from Bayer Corporation were needed on-site full-time. The amount of skilled labor may be reduced as this process becomes further developed.



1,920' Exposed Wet Applied Geotextile / Polyurethane Composite

Location Map
Rick Stone Ranch
Canal Lining Installation

Figure 1

Construction: The polyurethane resin consists of a mixture of polyol and isocyanate (about 2:1) with up to 10 percent accelerator, depending on the temperature. The Bayer chemists spent the first morning fine-tuning the mix proportions to achieve a gel time of 15-20 minutes, and settled on 5 percent accelerator to start the day (the chemicals were cool after sitting outside overnight). As the temperatures rose through the course of the day, the accelerator was gradually cut back to about 2 percent. The double layer of geotextile was run through a resin bath (dip pan) where it was saturated with liquid polyurethane. The 6-foot-wide membrane was then cut into lengths of approximately 16 feet. Four to six workers then carried the liner into the ditch and placed it over the existing concrete. The 6-foot width was perfect for this small ditch. The ditch perimeter was 5 feet, which allowed about 6 inches for placement into the anchor trench on each side. Although the machine can produce liner at speeds up to 16 feet per minute, the crew was capable of placing a 16-foot panel only every 2 minutes. Panels were shingled downstream and overlapped 6-12 inches. Three to five workers (including one IPC employee) then roll the liner into place, working out any bubbles and wrinkles, and pressing together the seams. The next day, batten strips were installed across the ditch every 100-150 feet, and polyurethane patching compound (Peter Putty) was mixed in 1-gallon baggies and used to patch around gated turn-outs and to perform minor repairs. A few gallons of polyurethane resin were left for the owner to perform any future repairs. The owner was also responsible for backfilling the anchor trenches.

Difficulties: Areas of broken concrete were covered with a double layer of polyurethane liner. The liner will stop the water seepage, and may prevent further collapse of the canal. This lining technique was very labor intensive, requiring 5-6 skilled workers from Canal Lining Systems, 1-2 chemists from Bayer Corporation, and 6-10 unskilled laborers who were hired locally. Once production began, the lining machine produced a 16-foot panel about every 2 minutes. The crew had to really hustle to keep up and could not stop for breaks. The lining machine was operated for 2 to 2½ hours at a time. When shutting down for lunch and at the end of the day, the dip tank was flushed with acetone. Because of the hard physical labor, the crew could work only 4-5 hours each day. Depending on carry distance, two crews might be needed per machine. Perhaps with four to six additional laborers, a full, 8-hour work day could be achieved. The polyurethane is quite messy and ruins the workers clothes; it is recommend that disposable coveralls and booties be provided.

Unit Cost Estimate: Exposed 40-mil wet-applied polyurethane over existing concrete = $1.43 ($0.75 Polyurethane Liner + 0.15 resin freight + 0.12 surface prep + 0.20 installation +17% OH and profit)

Note: This does not include costs of $5-$10,000 for the transport of the lining machine and IPC personnel.

Advantages: The 6-foot panel width was ideal for installation in this small, 5-foot perimeter, farm ditch. This liner is best suited for use over existing concrete because it bonds to the concrete to resist uplift. Bayer laboratory data shows bonded peel strength to smooth, clean concrete of 6-8 pounds per inch (appendix B). In the field, the liner did not appear to be continuously bonded to the concrete, and the peel strength to concrete, when applied under field conditions, appeared

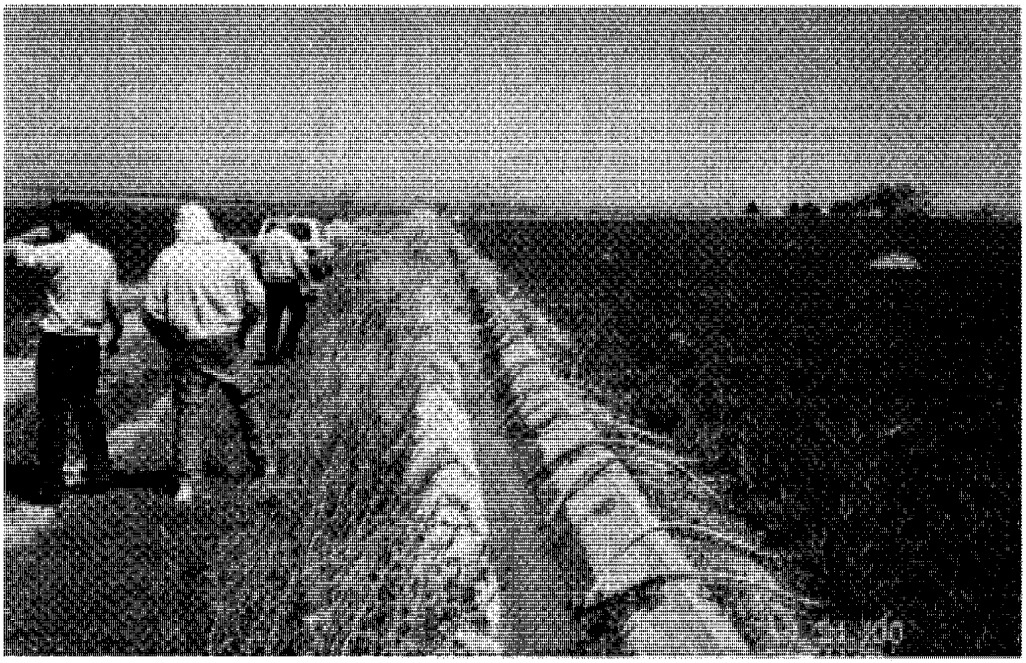
significantly lower (1 to 2 pounds per inch?). Reclamation data on laboratory testing of liner and seams prepared in the field is included in appendix C.

Disadvantages: Because this liner is manufactured in the field, consistency and quality control are less than they would be for a factory manufactured liner. Field manufactured liners are subject to variations of weather. Because the polyurethane reacts with water (foams), which reduces the bond and tensile strength, this liner absolutely cannot be installed in the presence of any rain or standing water. Wind also makes it very difficult to handle to the 6- by 16-foot wet panels, and the liner cannot be installed in winds above 20 mph. The 40,000-pound lining machine required good access to the canal.

The small panel size (6- by 16-foot) requires numerous field seams. Seaming is relatively easy, but Reclamation laboratory testing (appendix C) shows the seams are quite weak (peel strength of 1 to 2 pounds per inch).

Photographs: 1 through 22

Stone Ranch Farm Lateral – Test Section TF-1
Exposed 40-mil Wet-Applied Polyurethane Geocomposite over existing concrete

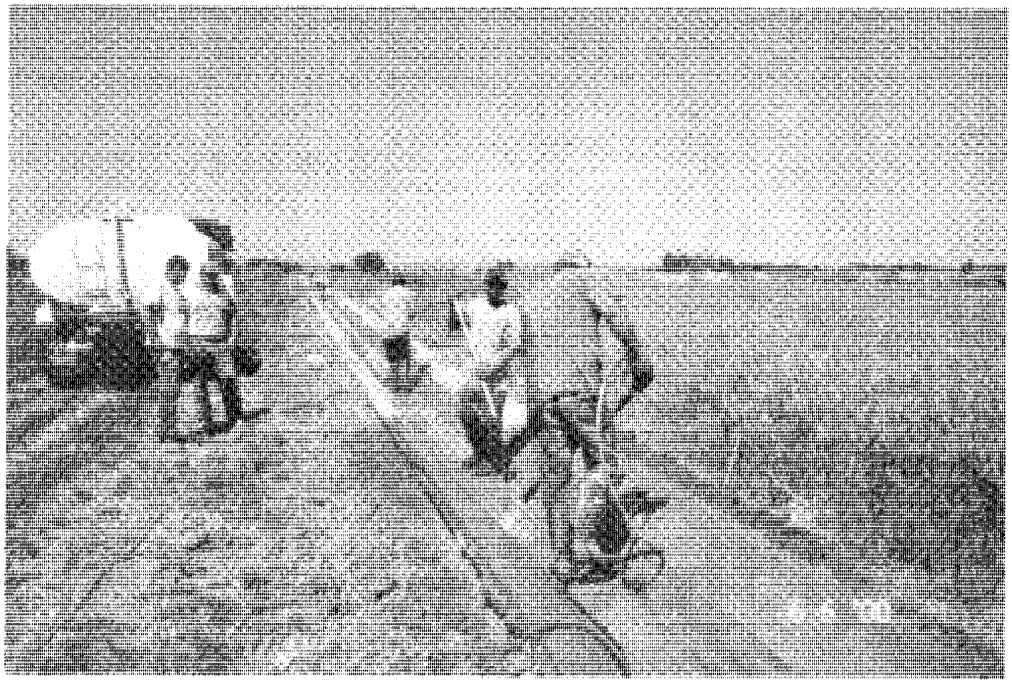


Photograph 1.—Existing concrete ditch with numerous cracks in the invert.

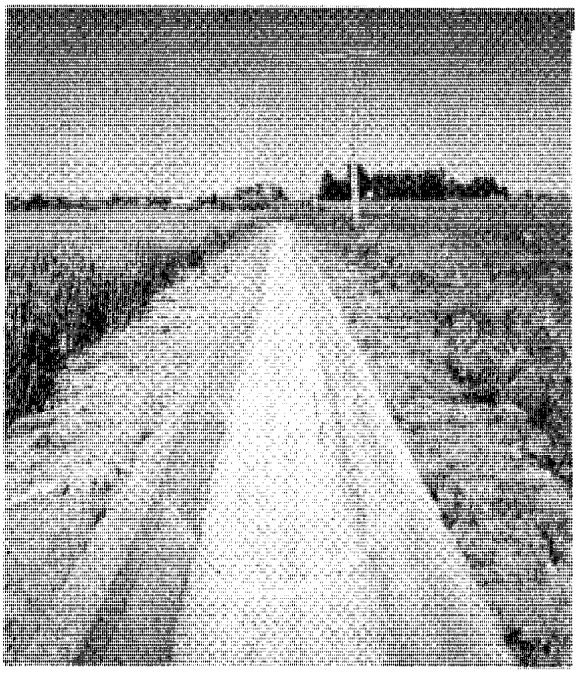


Photograph 2.—Some sections of the existing concrete are severely cracked with offsets up to 4 inches.

Stone Ranch Farm Lateral – Test Section TF-1
Exposed 40-mil Wet-Applied Polyurethane Geocomposite over existing concrete

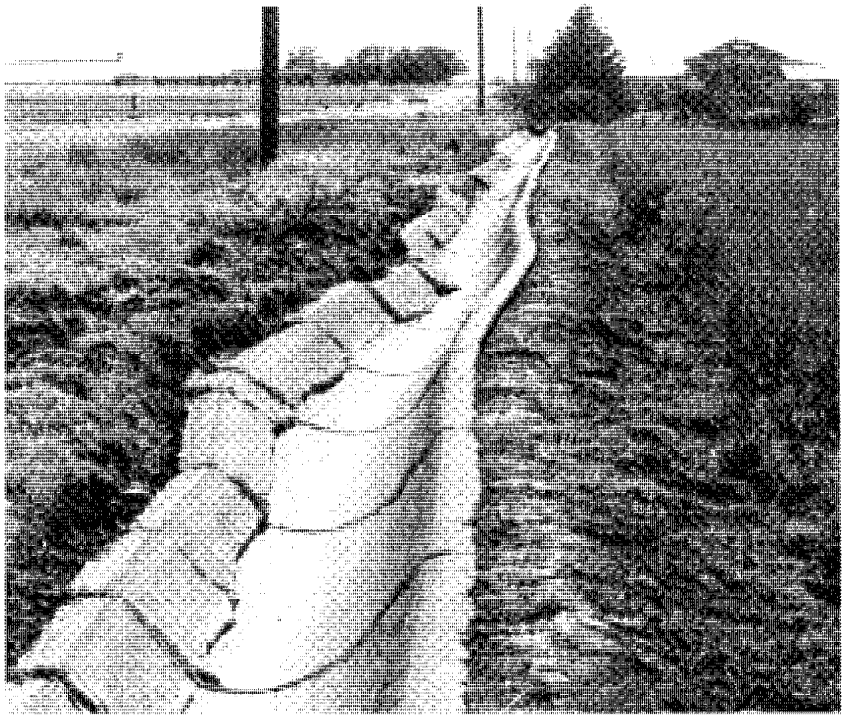


Photograph 3.—Power washing the ditch to remove dirt and sediment.



Photograph 4.—Ditch after power washing. Subgrade preparation complete.

Stone Ranch Farm Lateral – Test Section TF-1
Exposed 40-mil Wet-Applied Polyurethane Geocomposite over existing concrete



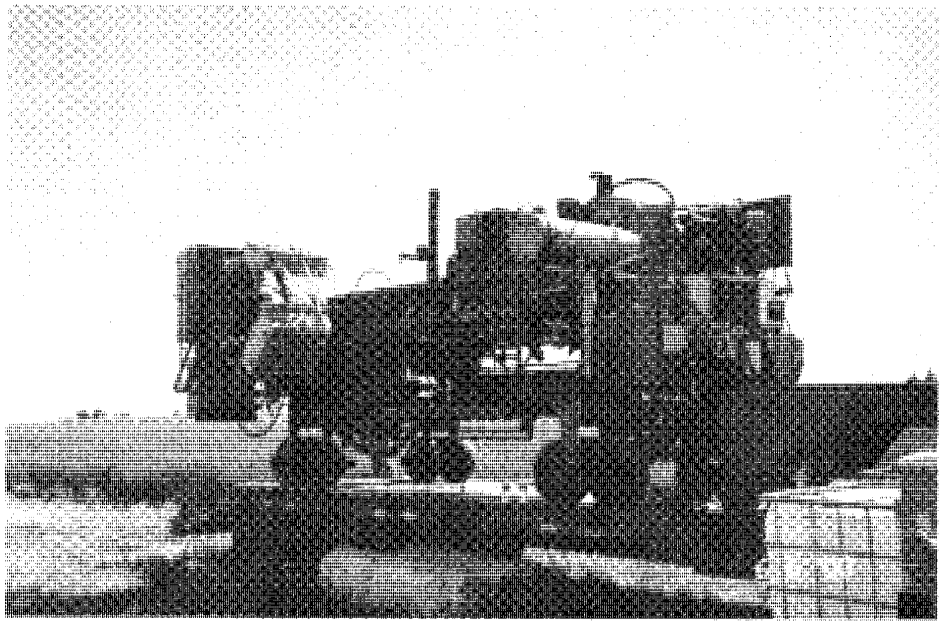
Photograph 5.—Severely cracked section after cleaning.



Photograph 6.—A section of the ditch where concrete panels are missing completely. A double layer of polyurethane liner will be installed over this section.

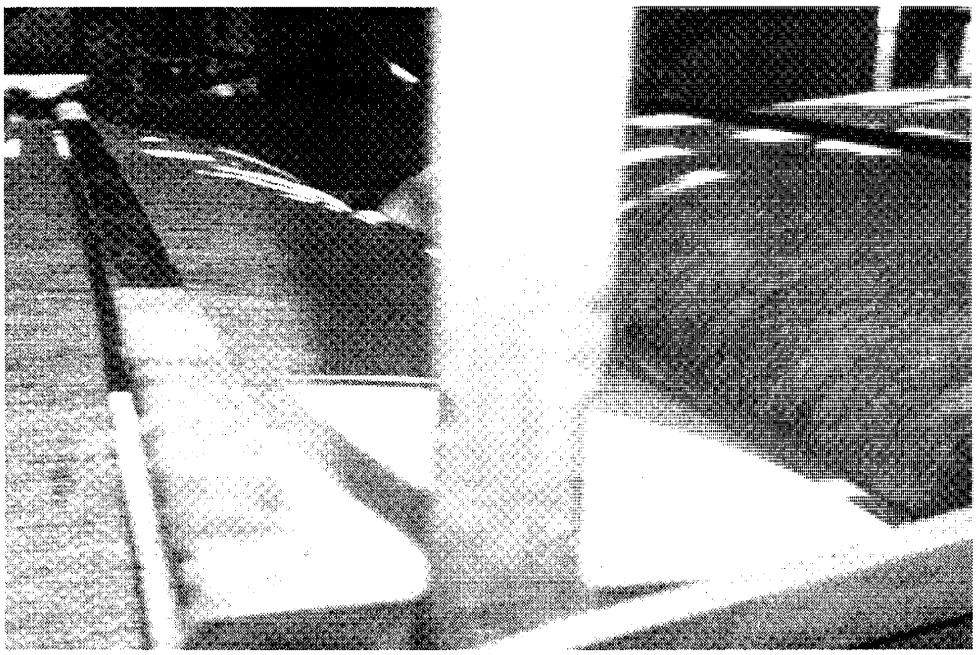


Photograph 7.—Before starting the job, chemists determine the proper mix ratios for Isocyanate, Polyol, and accelerator, depending on field conditions and temperatures.

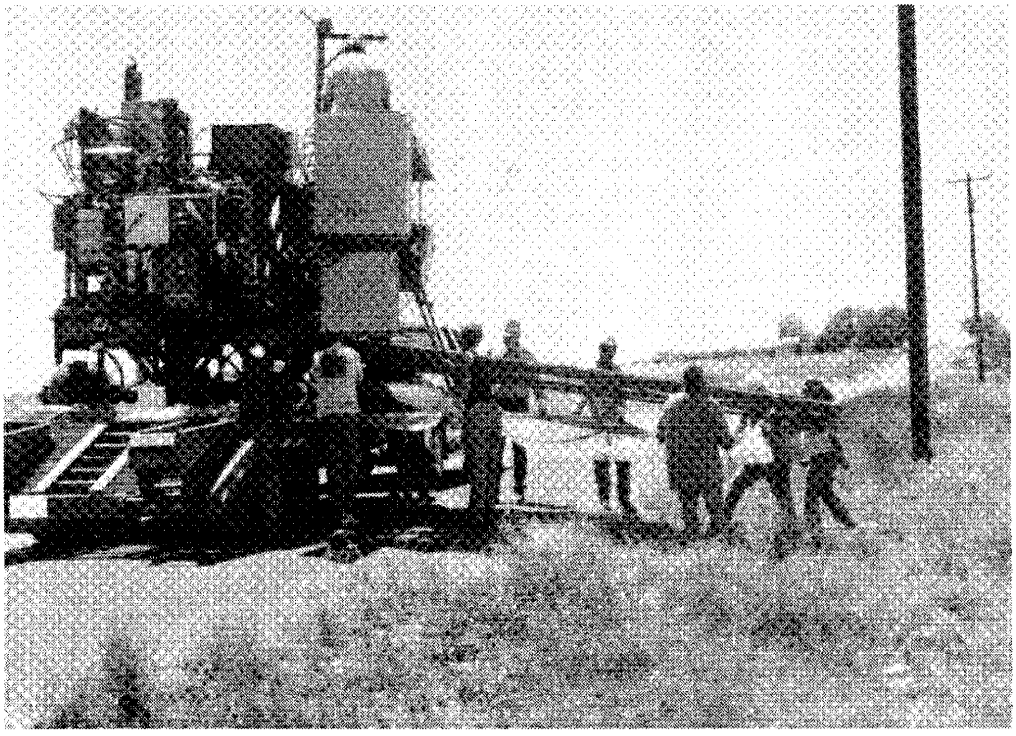


Photograph 8.—Lining machine on flatbed trailer.

Stone Ranch Farm Lateral – Test Section TF-1
Exposed 40-mil Wet-Applied Polyurethane Geocomposite over existing concrete

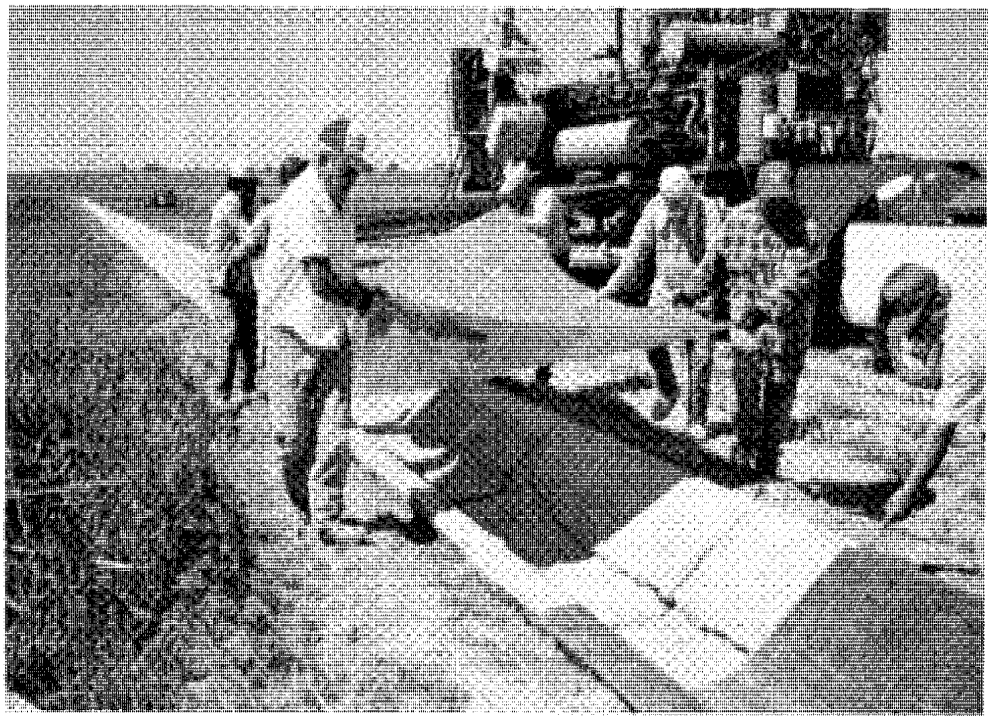


Photograph 9.—Two layers of geotextile are saturated with polyurethane resin as they pass through the dip pan.



Photograph 10.—Lining machine produces a 6- by 16-foot panel every 1 to 2 minutes.

Stone Ranch Farm Lateral – Test Section TF-1
Exposed 40-mil Wet-Applied Polyurethane Geocomposite over existing concrete

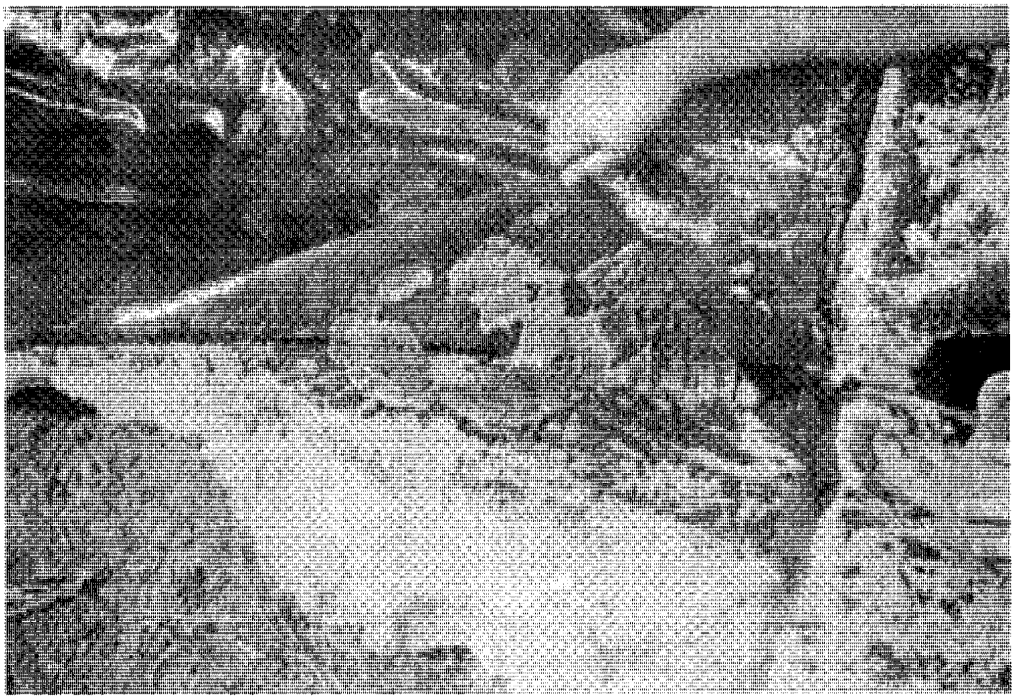


Photograph 11.—Crew lays the 6- by16-foot panel over the existing concrete.



Photograph 12.—Laborers use rollers to work out wrinkles and improve adhesion to the concrete.

Stone Ranch Farm Lateral – Test Section TF-1
Exposed 40-mil Wet-Applied Polyurethane Geocomposite over existing concrete



Photograph 13.—The liner is partially bonded to the old concrete. Foaming of the Polyurethane is caused by reaction with water

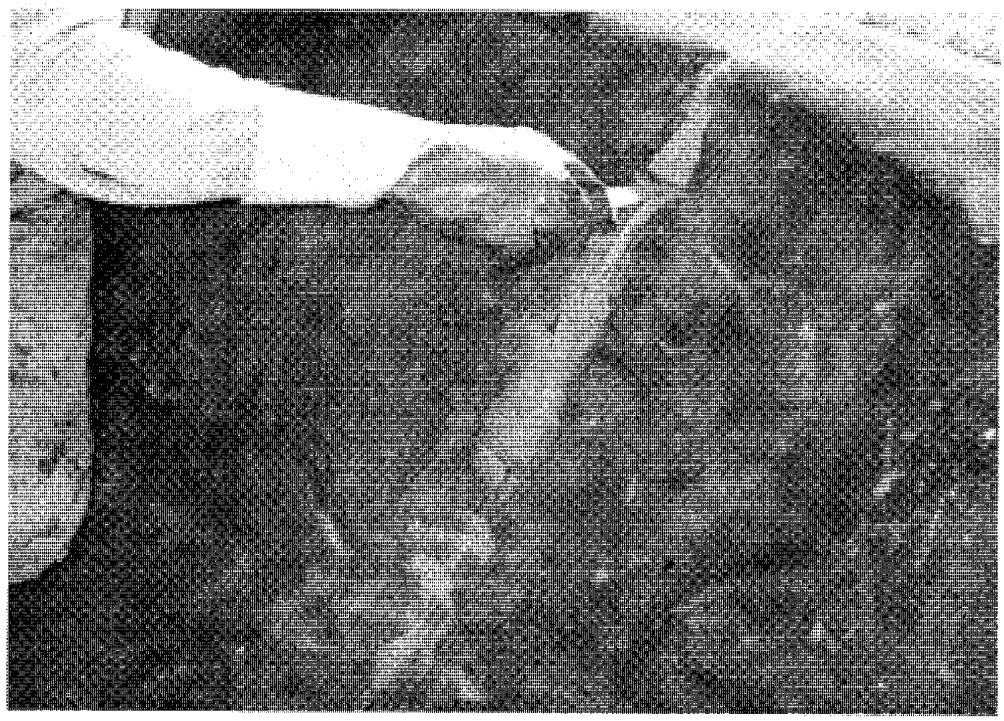


Photograph 14.—Large wrinkles were cut open and patched.

Stone Ranch Farm Lateral – Test Section TF-1
Exposed 40-mil Wet-Applied Polyurethane Geocomposite over existing concrete



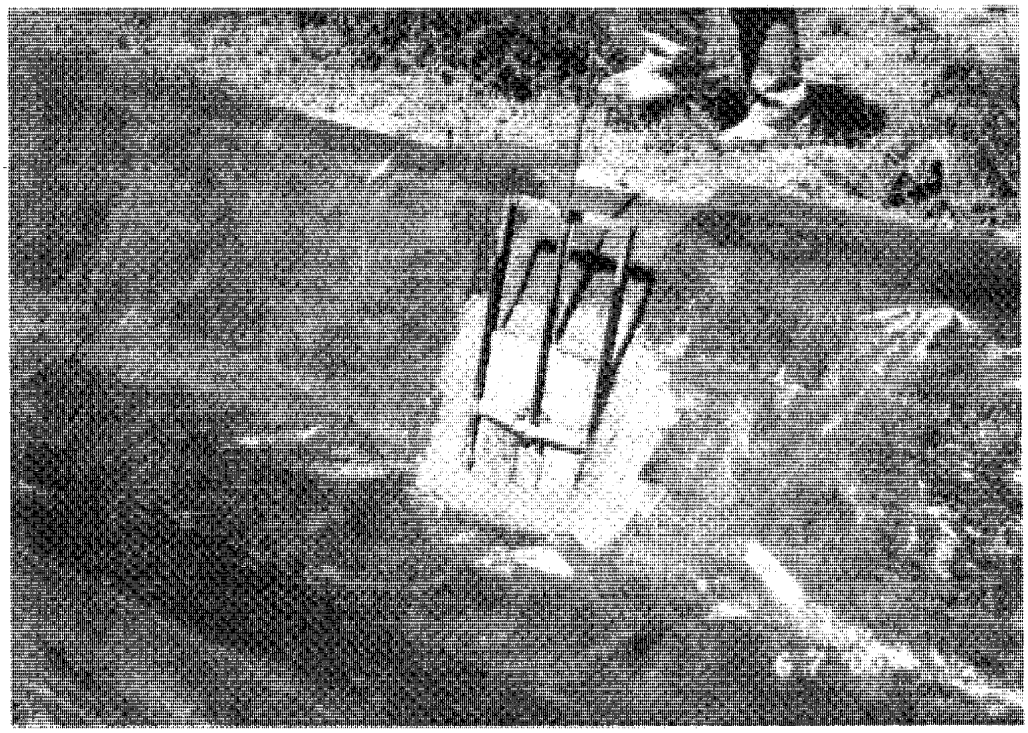
Photograph 15.—The chemists used a polyurethane patching compound to repair problem areas.



Photograph 16.—Chemist uses putty knife to trowel the patching compound.



Photograph 17.—Patching compound was used to bond the liner around slide gate turnouts.

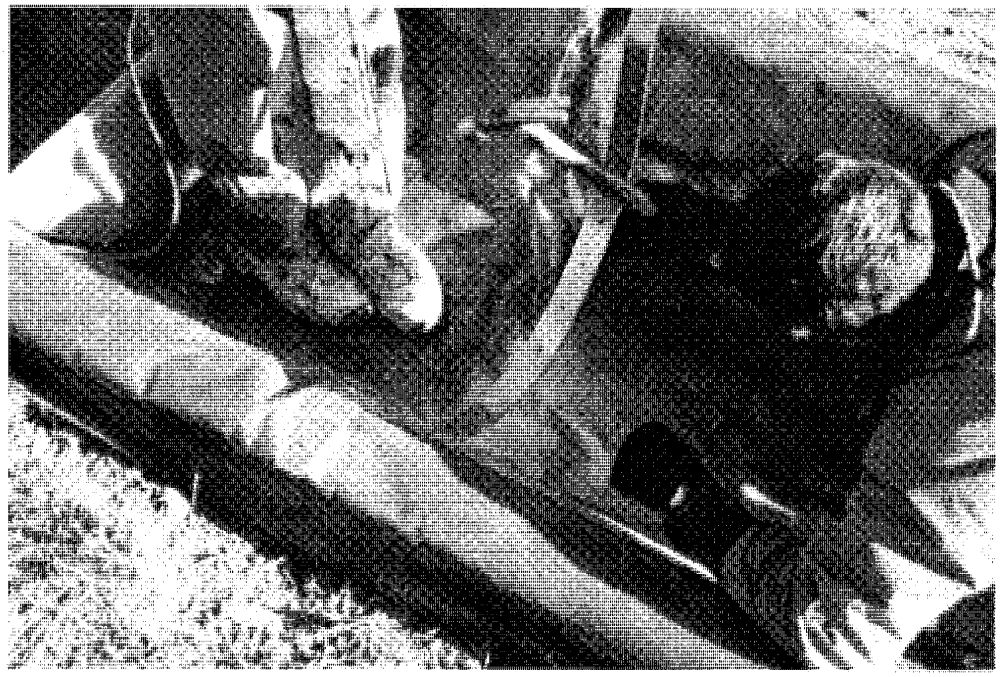


Photograph 18.—Slide gate turnout with patching compound.

Stone Ranch Farm Lateral – Test Section TF-1
Exposed 40-mil Wet-Applied Polyurethane Geocomposite over existing concrete



Photograph 19.—Batten strips were attached by pre-drilling holes and driving concrete anchors.



Photograph 20.—After pre-drilling, the 2-inch concrete anchors are easily hammered into the concrete. The 2-inch-wide batten strip is 16 gage stainless steel.

Stone Ranch Farm Lateral – Test Section TF-1
Exposed 40-mil Wet-Applied Polyurethane Geocomposite over existing concrete



Photograph 21.—The polyurethane liner conforms to concrete with offsets in the invert of up to 4 inches. The liner is ready to be secured by backfilling the anchor trench.



Photograph 22.—Ditch after installation was completed.

Test Section LO-1.—

Material:	Exposed 45-mil reinforced Metallocene with 8-oz geotextile cushion
Date Installed:	October 2000
Location:	Lewiston Orchards - about 10 miles southeast of Lewiston Idaho (figure 2) (1500 + 300 linear feet, 36,000 square feet)
Description:	The 45-mil geomembrane consists of two layers of Metallocene reinforced with a 10 by 10 polyester scrim. The geomembrane is tan on the top side and black on the bottom. Metallocene is a copolymer blend of HDPE and Polypropylene. The material data sheet is included in appendix A.
Prime Contractor:	Lewiston Orchards Irrigation District (LOID)
Material Supplier:	Serrot Corporation
Surface Preparation:	The irrigation district performed extensive subgrade preparation by removing vegetation from the canal, restoring the approximately 1½:1 side slopes and cutting a 2-foot wide bench for anchoring on each bank. The cost of subgrade preparation is estimated at \$0.26 per ft^2, based on the subgrade preparation costs of previous, similar test sections. The finished canal prism measures 20 to 24 feet across, including the 1 to 2 feet of material buried in the anchor berm on each bank. The finished canal invert measures 6 to 8 feet across, and the 1½:1 side slopes measure 3 to 4 feet high. Water typically runs about 2 feet deep, and this section of canal typically carries about 23 cfs. Seepage was estimated at 1 to 2 cfs and is quite evident in one bend where lots of vegetation is growing below the canal. The irrigation district also improved the access road by hauling in rock and gravel, and then grading the road. The road is only on one side of the canal. These costs are not included in the cost estimates.
Construction:	The Metallocene geomembrane is manufactured in 10-foot-wide rolls. The roll goods were then fabricated into 30- by 100-foot panels. The panels were folded toward the middle, and rolled onto the 10-foot cardboard core. A trackhoe was used to pre-position the panels and geotextile cushion along the canal. An eight-man crew installed the geomembrane. The crew first rolled out the geotextile cushion in the road and then pulled it into place. The crew then rolled out the geomembrane along the road, unfolded it, and pulled it into place, securing it temporarily with 3/8 inch rebar bent into a 1-foot-long pin. The trackhoe then covered the anchor berm with 6 to 12 inches of cover soil and rock. The geomembrane panels were shingled downstream, overlapped 1 to 2 feet, and welded with a hot-air gun and hand roller. Before seaming, the geomembrane was cleaned with wet cloth. Serrot provided a master welder.

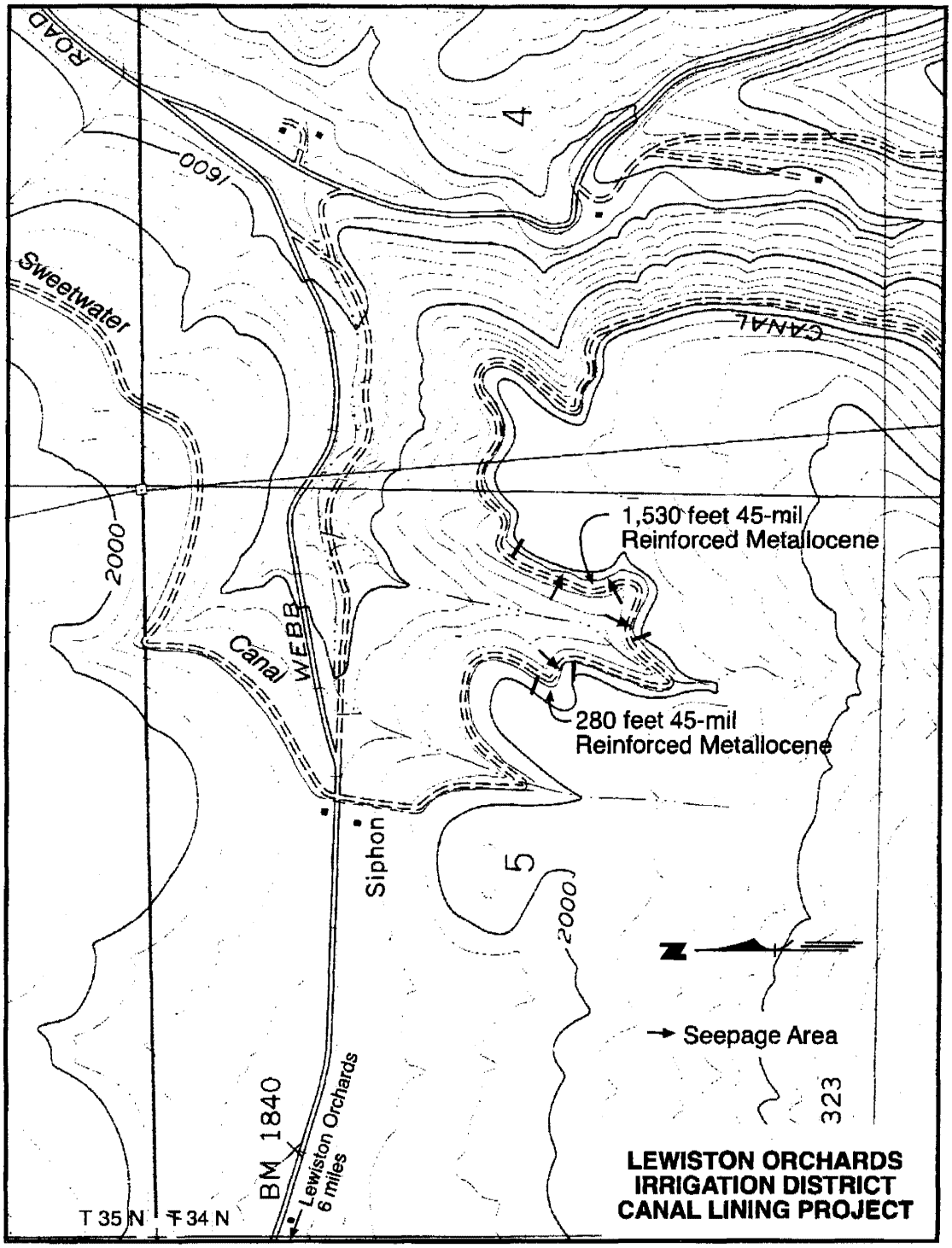
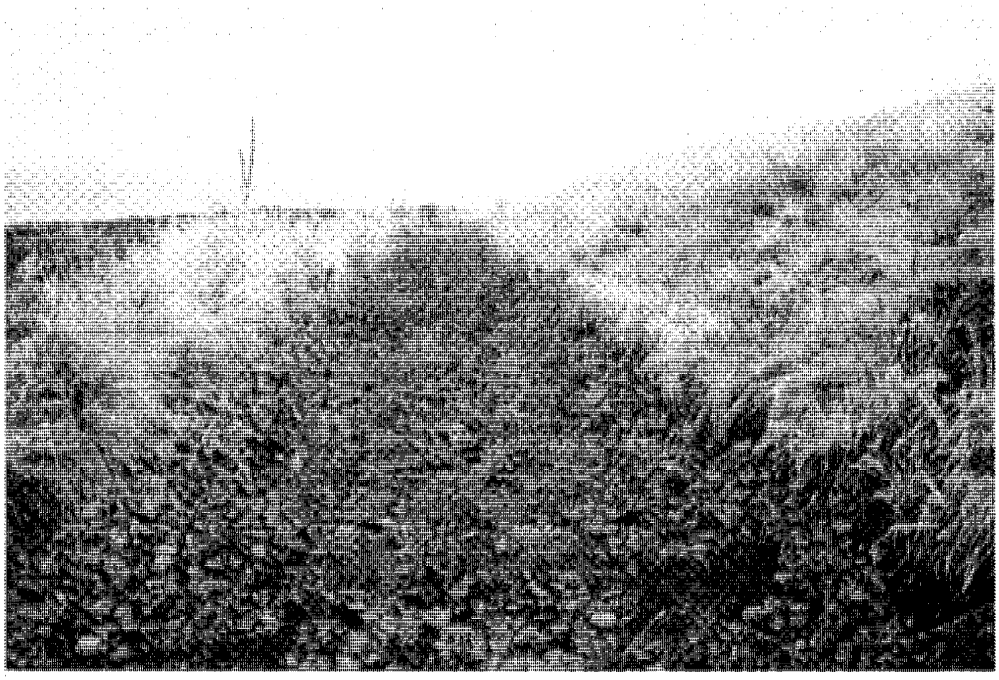


Figure 2 – Location Map

	The first 600 feet of canal was quite rocky and was covered with a 16-oz geotextile cushion or excess scraps of Metallocene. The rest of the canal was much smoother, and cushion was placed in the invert only. Because of the liner flexibility, only the rockiest sections really needed the cushion. The cost estimate assumes an 8-oz geotextile cushion used everywhere.
Difficulties:	The wedge welder would not work on steep side slopes and over the rough subgrade. Also, there were problems with water in the canal invert. To get the liner up out of the mud, the welding was performed on 2- by 8-foot sheets of plywood. In the worst areas, a pump or wet-vac was used to dry out the canal invert before seaming.
Unit Cost Estimate:	Exposed 45-mil reinforced Metallocene with 8-oz geotextile cushion = $1.00 per ft^2. ($0.39 Metallocene + 0.10 Geotextile cushion + 0.26 surface prep + 0.10 installation +17% OH and profit)
Advantages:	The liner was very flexible and conformed to the subgrade easily. The 100-foot panels were easy to pull into place. A couple of panels were cut to fit around sharp bends in the canal, leaving welded seams every 50 to 100 feet. To minimize seaming on long sweeping bends, the liner was pleated and folded downstream. The only heavy equipment required was the trackhoe, which prepared the subgrade and unloaded and pre-positioned the rolls of geomembrane and geotextile cushion. The district should be able to perform minor repairs using a $500 hot air welder.
Disadvantages:	Because the panels were fabricated into 30-foot widths and the canal prism varied from 20 to 24 feet, a lot of excess material was trimmed and wasted. The excess material was used as cushion in the invert, but it makes a very expensive cushion compared to 8 oz geotextile. A skilled welder was also needed at $500+ per day to weld the field seams
Photographs:	1 through 22

Lewiston Orchards Irrigation District – Test Section LO-1
Exposed 45-mil Reinforced Metallocene



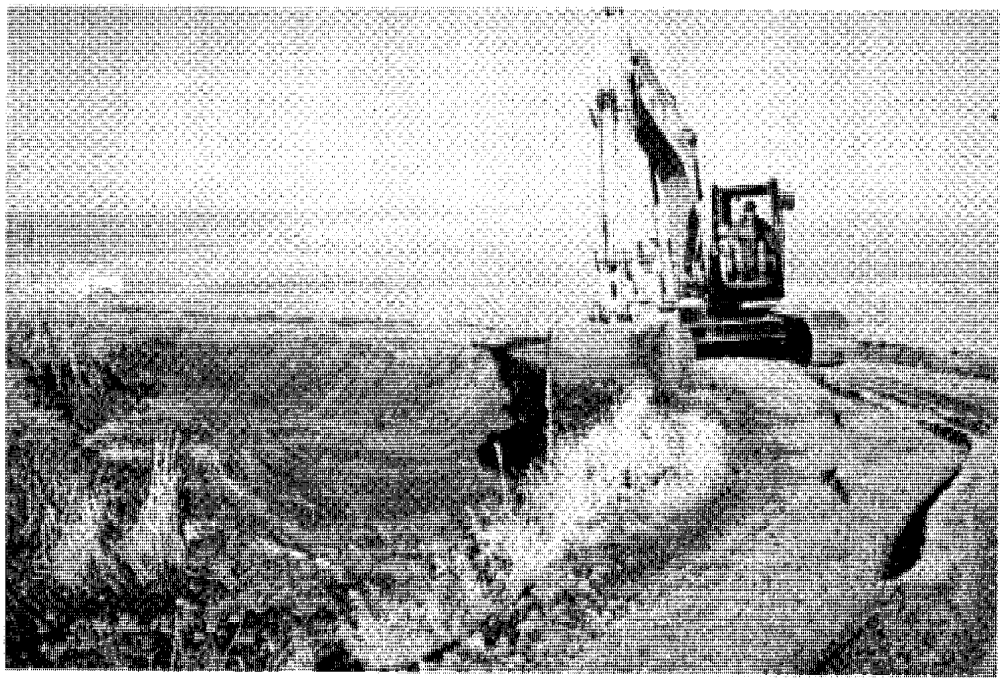
Photograph 1.—Preconstruction conditions at Lewiston Orchards. Subgrade consists of angular volcanic basalt.



Photograph 2.—Irrigation district removed a couple of abandoned pipe crossings to facilitate lining installation.



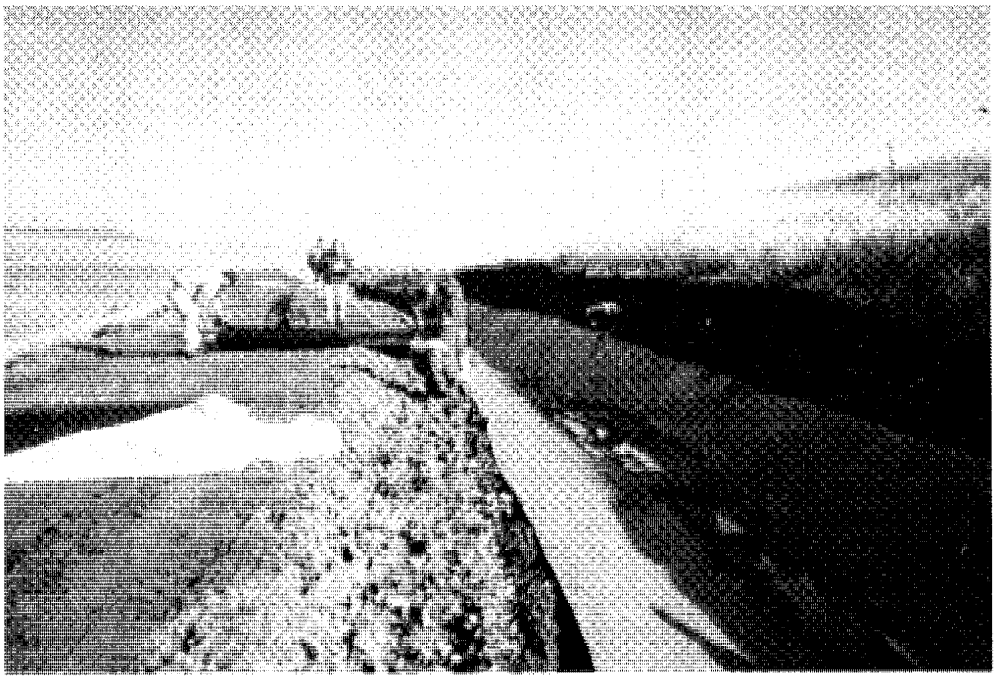
Photograph 3.—Trackhoe reshapes the canal prism, restoring the 1½:1 side slopes.



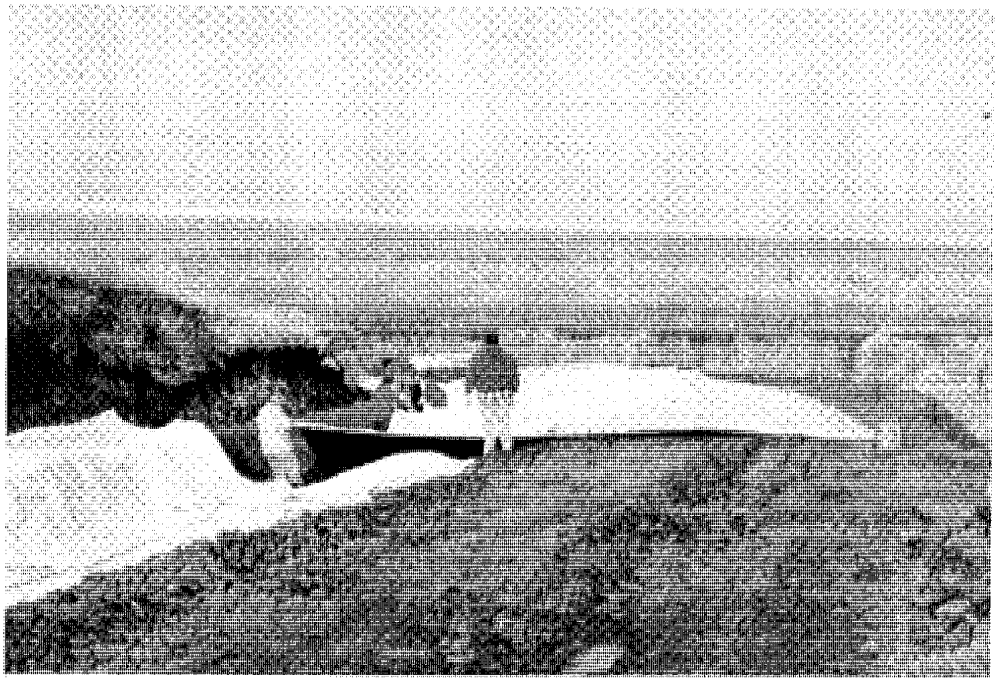
Photograph 4.—Trackhoe cuts 3-foot anchor berm into both banks.



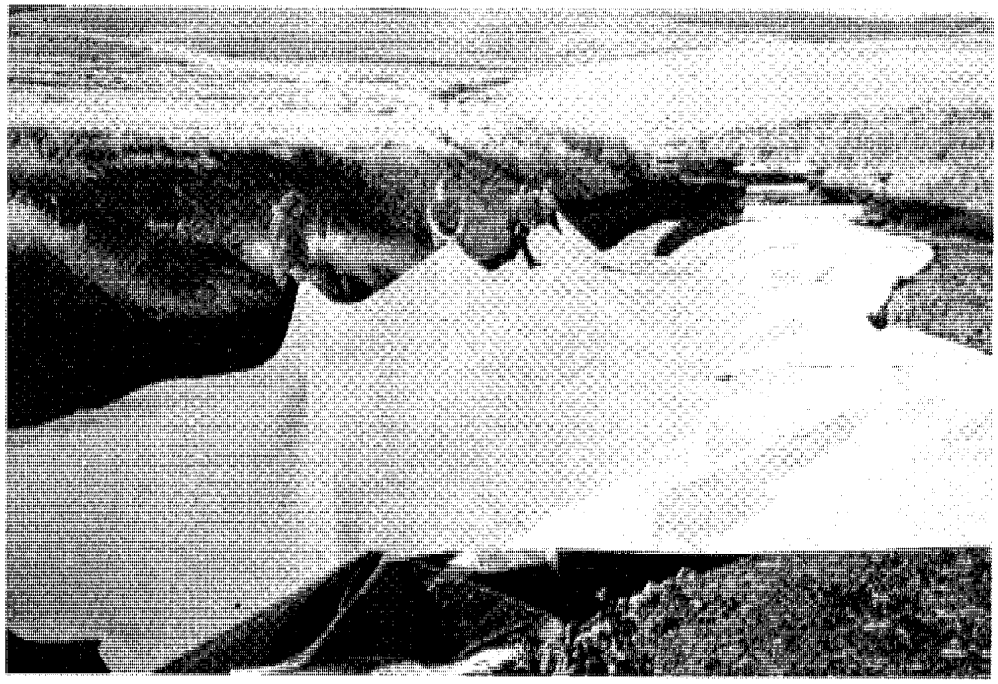
Photograph 5.—Trackhoe positions roll of geotextile cushion along the access road.



Photograph 6.—Geotextile cushion has been placed in the canal invert. The installation crew unrolls the Metallocene in the access road.



Photograph 7.—Crew unfolds the Metallocene and pulls the panel into place.



Photograph 8.—Installation crew pulls the Metallocene up the far bank and into final position.



Photograph 9.—At the downstream end, the liner is placed into a 3-foot-deep cut-off trench.



Photograph 10.—Liner is ready for seaming.



Photograph 11.—Liner is temporarily secured on the anchor berm with #3 rebar stakes.



Photograph 12.—To minimize seaming, the liner was folded around bends in the canal alignment.



Photograph 13.—Wet-Dry Vac used to remove ponded water before seaming.

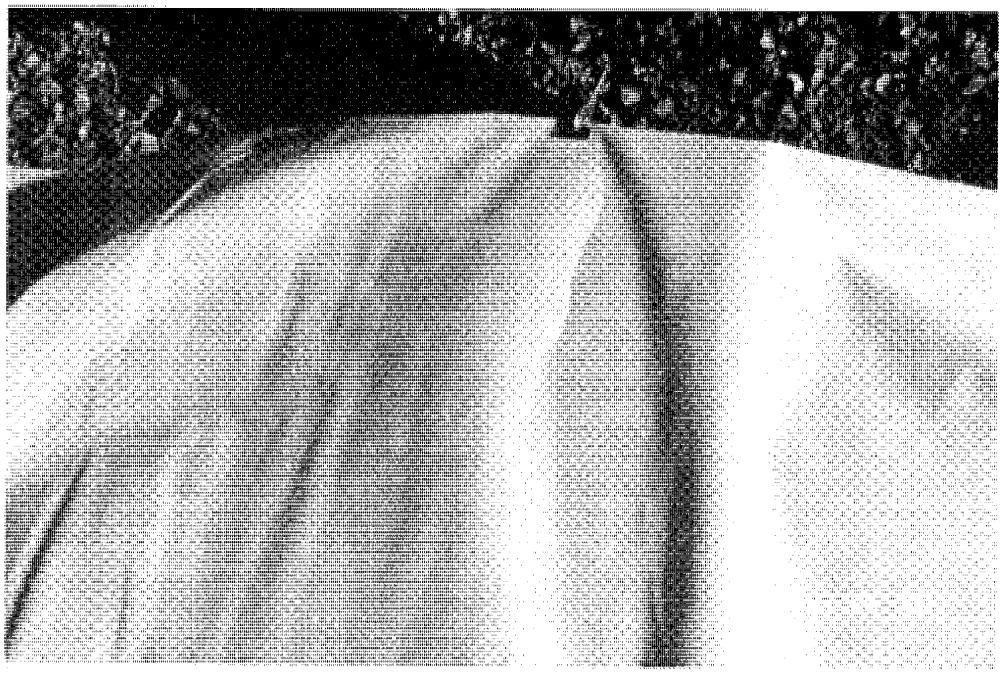


Photograph 14.—Overlapped seams are cleaned to remove dirt and mud before seaming.

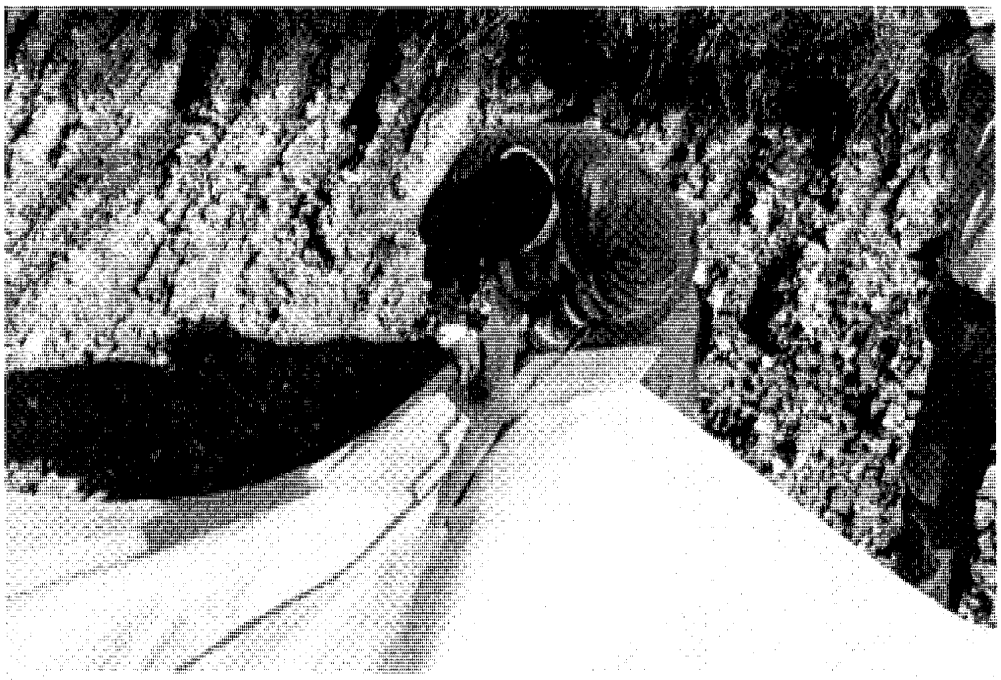
Lewiston Orchards Irrigation District – Test Section LO-1
Exposed 45-mil Reinforced Metallocene



Photograph 15.—Master welder from Serrot uses hot-air welder to seam the Metallocene.



Photograph 16.—Plywood (not visible) is temporarily placed under the liner to provide a firm surface for seaming. Overlapped seams are clamped into final position for seaming.



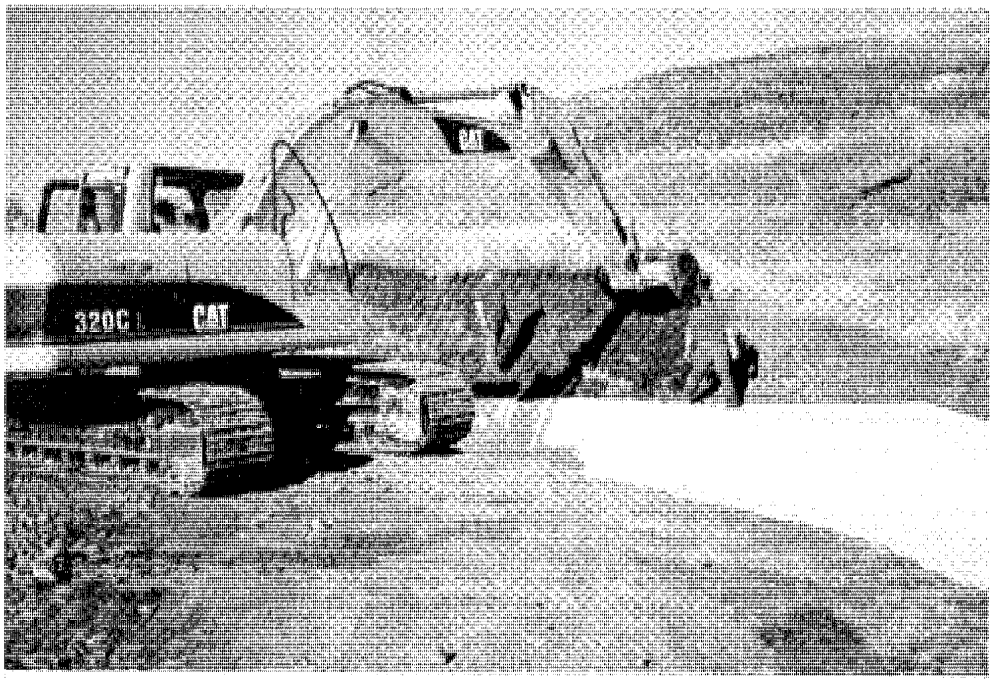
Photograph 17.—As the seaming is completed, the plywood is removed.



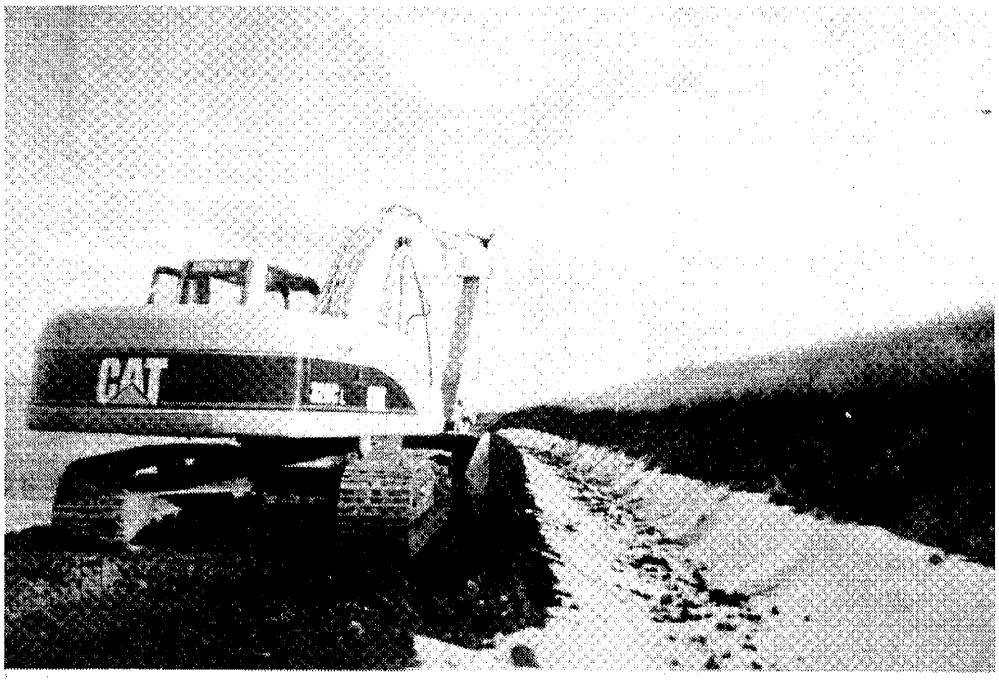
Photograph 18.—The master welder places a large patch over a problem seam.



Photograph 19.—Irrigation district personnel are trained in proper seaming techniques for any future repairs.



Photograph 20.—Trackhoe places cover material over the far anchor berm.



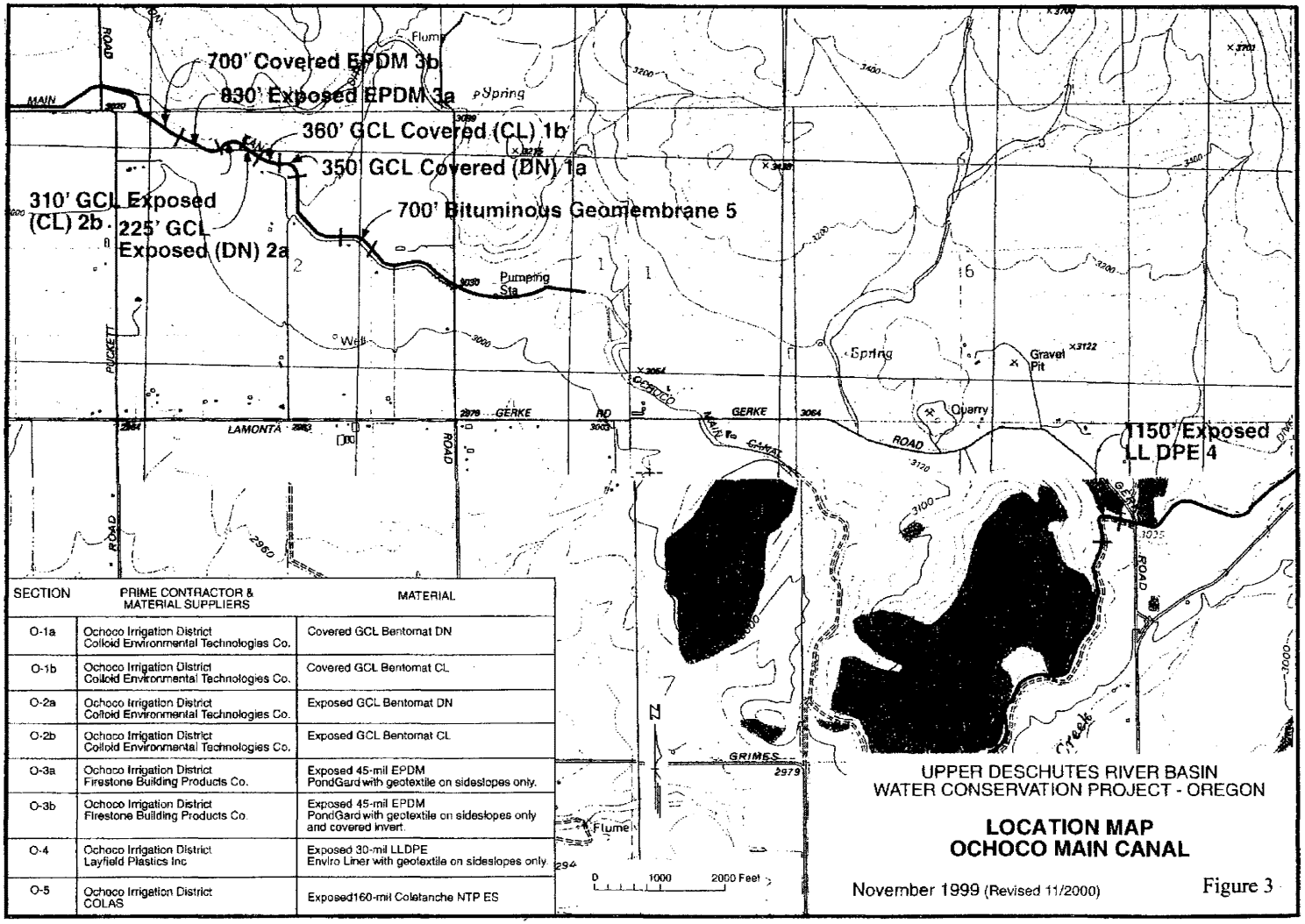
Photograph 21.—Additional road base was imported to restore the access road and to cover the near anchor berm.



Photograph 22.—Finished Metallocene installation.

Test Section O-5.—

Material:	Exposed 160-mil Coletanche NTP ES
Date installed:	November 2000
Location:	Ochoco Irrigation District (figure 3) (700 linear feet; 28,000 square feet)
Description:	Coletanche NTP ES (Coletanche) is an elastomeric bitumen geomembrane, combining Styrene-Butadiene-Styrene (SBS) polymer and asphalt with a polyester reinforcement. COLAS manufactures five grades of Coletanche. Only the Coletanche ES is polymer modified. Coletanche is 160-mils thick and is provided in roll widths of 4 and 5 meters (13 and 16.5 feet). Product data sheets are included in appendix A.
Prime Contractor:	Ochoco Irrigation District
Material Supplier:	COLAS, Inc. (France)
Subgrade prep:	Ochoco personnel performed extensive subgrade preparation by removing vegetation that had overgrown the canal. They removed 6 to 12 inches of mucky sediment and restored the original 1½:1 side slopes. The cost for extensive subgrade preparation is estimated at \$0.26 per ft^2. This subgrade estimate was based on the subgrade costs of previous, similar test sections. The finished canal prism measures about 40 to 42 feet across, including a 1-foot V-notch anchor trench on each bank.
Construction:	Installation began at the downstream end of the test section and proceeded upstream 700 linear feet. The Coletanche was delivered in rolls measuring 5 by 80 meters (16½ by 262 feet), and the rolls were installed across the canal. The Coletanche rolls were handled by a trackhoe equipped with a lifting bar (constructed by the district). The Coletanche was first unrolled 4 to 5 feet by hand and clamped between 2 by 4s with a pair of C-clamps. A chain connected the C-clamps to a backhoe on the opposite bank. The backhoe then drove away from the canal, unrolling the Coletanche into place. The Coletanche was then cut to match the canal width and pulled into final position by a four-man crew. Adjacent sheets were overlapped 6 to 12 inches, shingled downstream, and seamed with a propane torch by a two-man crew. Finally, the membrane was secured in the berm by nailing, and then backfilled with 6-12 inches of cover soil in the V-notch anchor trench. At the upstream and downstream ends of the test section, the Coletanche was buried in a 2-foot- by 5-foot-wide cut-off trench. The upstream cut-off was backfilled with concrete, and the downstream was backfilled with soil.
Difficulties:	The subgrade was quite irregular, with offsets of up to 6 inches. Seaming over these large offsets was challenging.



SECTION	PRIME CONTRACTOR & MATERIAL SUPPLIERS	MATERIAL
O-1a	Ochoco Irrigation District Colloid Environmental Technologies Co.	Covered GCL Bentomat DN
O-1b	Ochoco Irrigation District Colloid Environmental Technologies Co.	Covered GCL Bentomat CL
O-2a	Ochoco Irrigation District Colloid Environmental Technologies Co.	Exposed GCL Bentomat DN
O-2b	Ochoco Irrigation District Colloid Environmental Technologies Co.	Exposed GCL Bentomat CL
O-3a	Ochoco Irrigation District Firestone Building Products Co.	Exposed 45-mil EPDM PondGard with geotextile on sideslopes only.
O-3b	Ochoco Irrigation District Firestone Building Products Co.	Exposed 45-mil EPDM PondGard with geotextile on sideslopes only and covered invert.
O-4	Ochoco Irrigation District Layfield Plastics Inc	Exposed 30-mil LLDPE Enviro Liner with geotextile on sideslopes only.
O-5	Ochoco Irrigation District COLAS	Exposed160-mil Colatanche NTP ES

UPPER DESCHUTES RIVER BASIN
WATER CONSERVATION PROJECT - OREGON

LOCATION MAP
OCHOCO MAIN CANAL

November 1999 (Revised 11/2000)

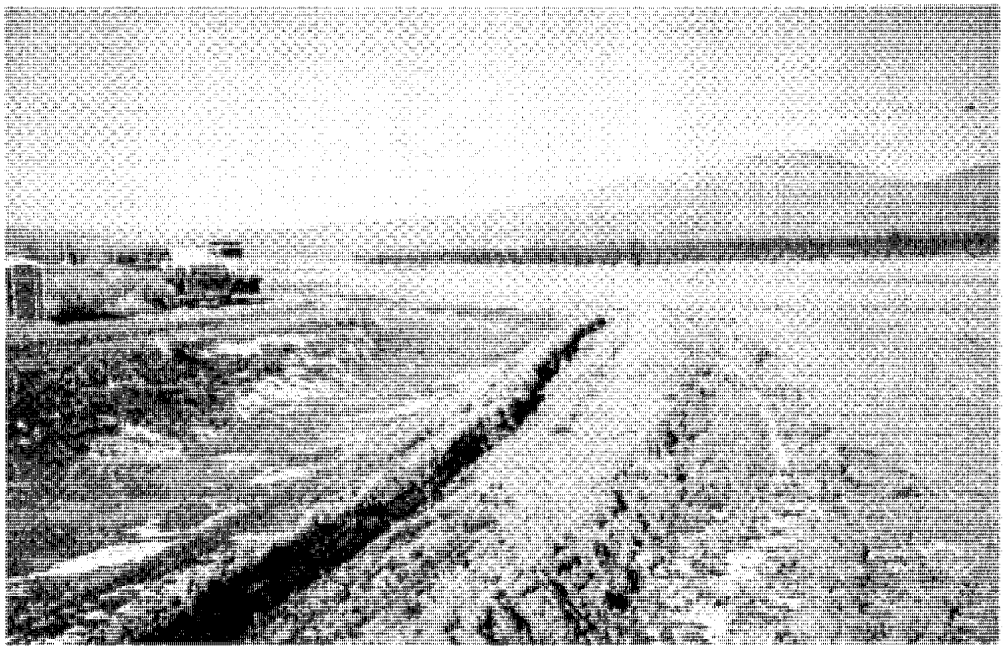
Figure 3

Unit Cost Estimate:	Exposed 160-mil Coletanche = $1.51 per ft^2 ($0.93 Coletanche + 0.26 preparation + 0.10 installation + 17% overhead (OH) and profit)
Advantages:	Coordinating the movements of the trackhoe and the backhoe on opposite banks allowed precise positioning of the Coletanche, and little to no handling was required. Because each panel of the Coletanche was trimmed to match the canal prism, little to no material was wasted. Installation was fast and simple and required no special equipment. Irrigation districts can install this material with their own forces, thus allowing flexibility in the construction schedule to accommodate bad weather and fluctuating workload. This crew had experience installing other geomembranes and was able to install 32,000 square feet (7½ rolls) on the first day. By using their own equipment and labor, the irrigation district was able to install the membrane at significantly less cost than hiring a contractor.
Disadvantages:	Because the Coletanche was installed across the canal, a transverse seam was needed every 5 meters along the canal. Seaming was rather slow, and two seaming crews were needed to keep pace with the installation crew. Exposed geomembranes are susceptible to weathering (especially UV light), animal damage, and vandalism. The Coletanche is UV resistant, and quite resistant to animal damage. Based on our experience with similar products, the expected service life is 20 to 40 years.
Photographs:	1 through 23

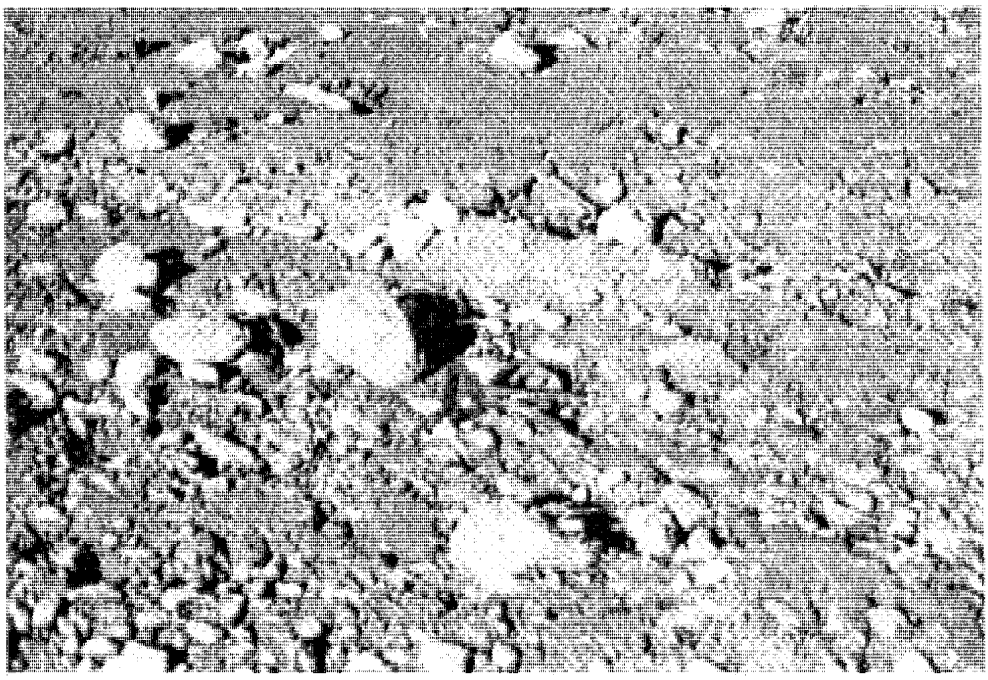


Photograph 1.—Earthen dike at upstream end of the test section. Preconstruction conditions are visible upstream from the dike.

Ochoco Irrigation District – Test Section O-5
Exposed 160-mil Coletanche NTP 2 ES

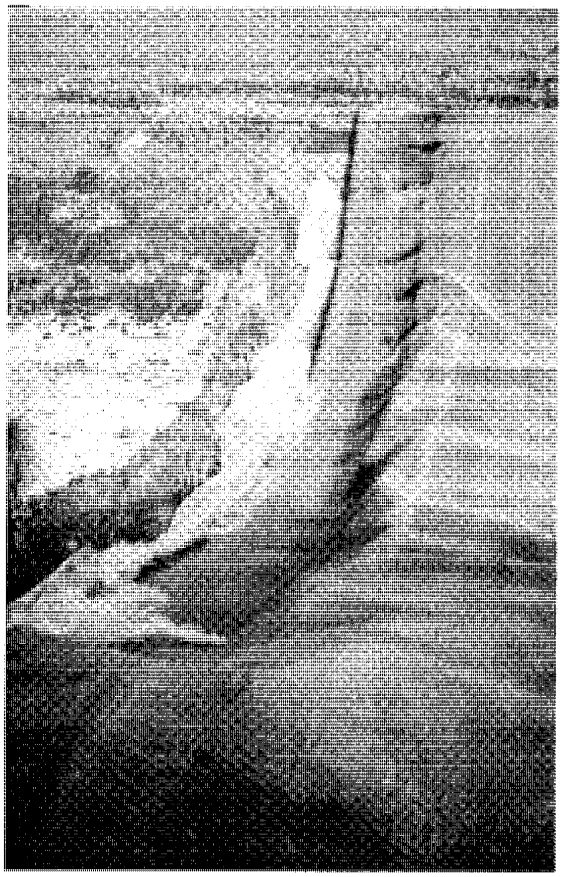


Photograph 2.—The irrigation district reshaped the canal prism, restored the 1½:1 side slopes, and cut a 6-inch deep V-notch anchor trench on each bank.



Photograph 3.—The subgrade was quite rough, and offsets were up to 6 inches.

Ochoco Irrigation District – Test Section O-5
Exposed 160-mil Coletanche NTP 2 ES

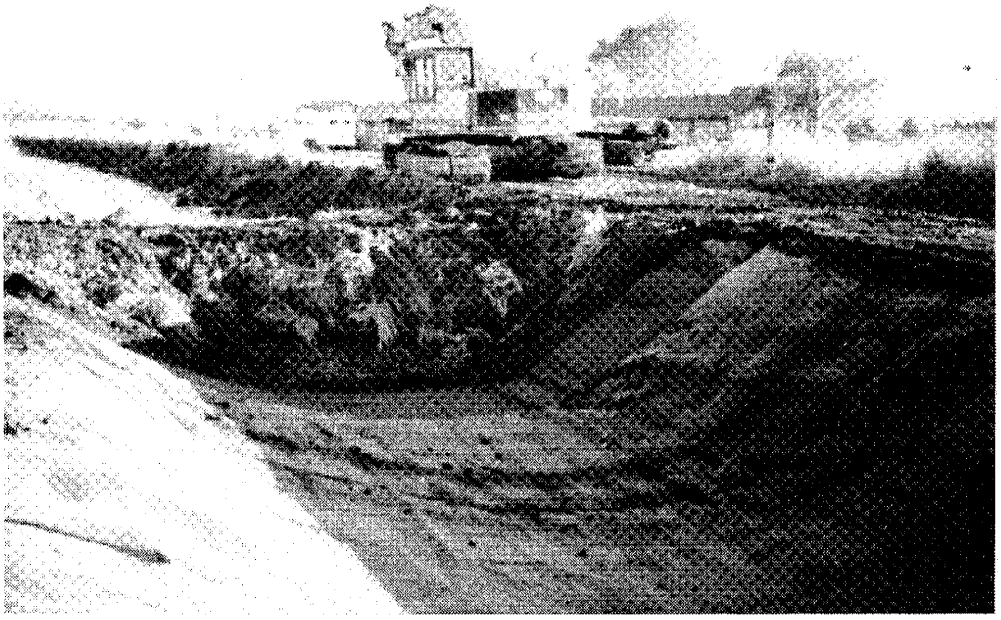


Photograph 4.—Geomembrane is placed in the cut-off trench at the downstream end of the test section.

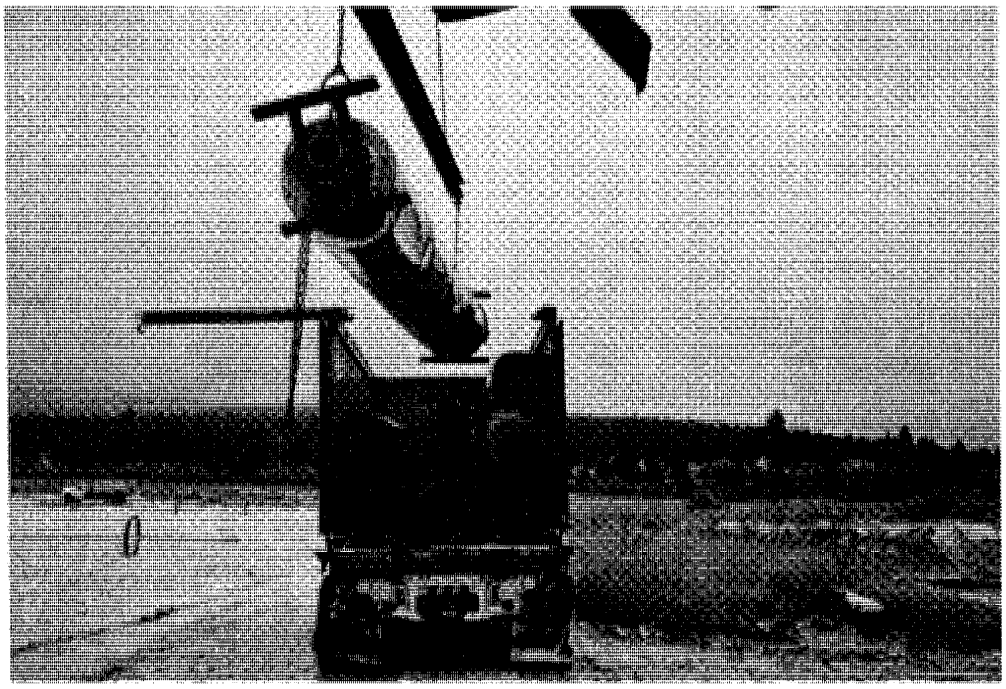


Photograph 5.—Concrete placed over geomembrane in the upstream cut-off trench.

Ochoco Irrigation District – Test Section O-5
Exposed 160-mil Coletanche NTP 2 ES



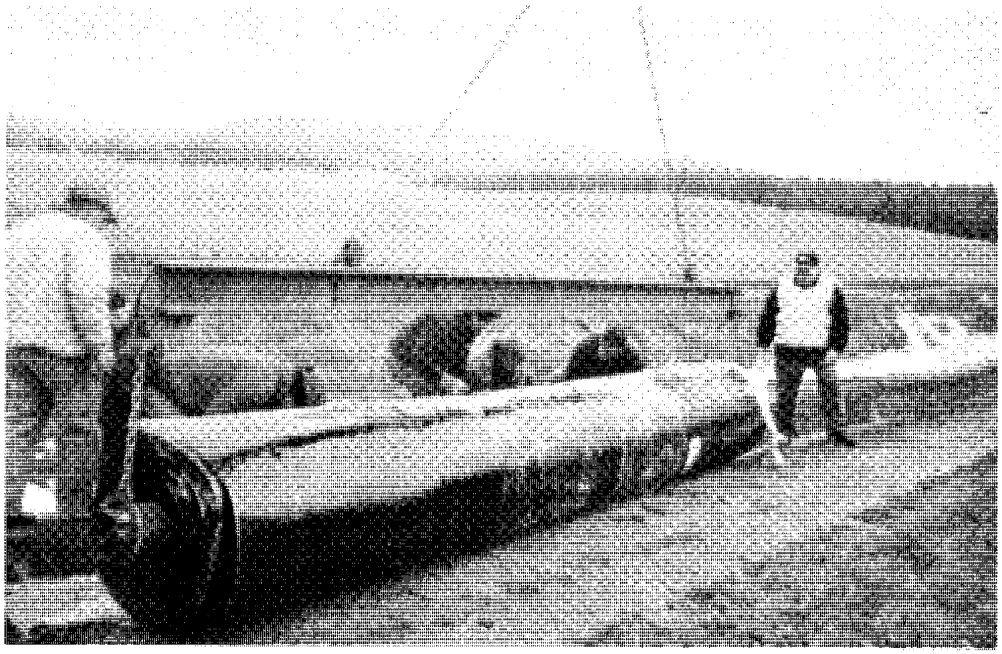
Photograph 6.—Completed upstream cut-off trench.



Photograph 7.—Trackhoe unloads rolls of Colas geomembrane from shipping container.



Photograph 8.—Trackhoe equipped with lifting bar (fabricated by the irrigation district) handles the rolls of geomembrane.

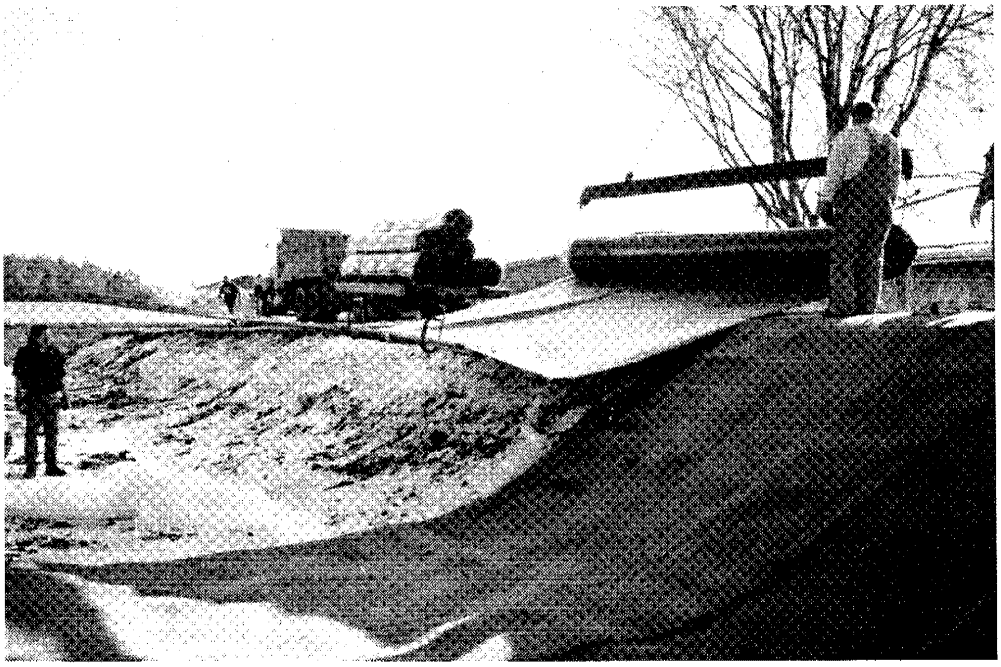


Photograph 9.—Close-up of lifting bar.

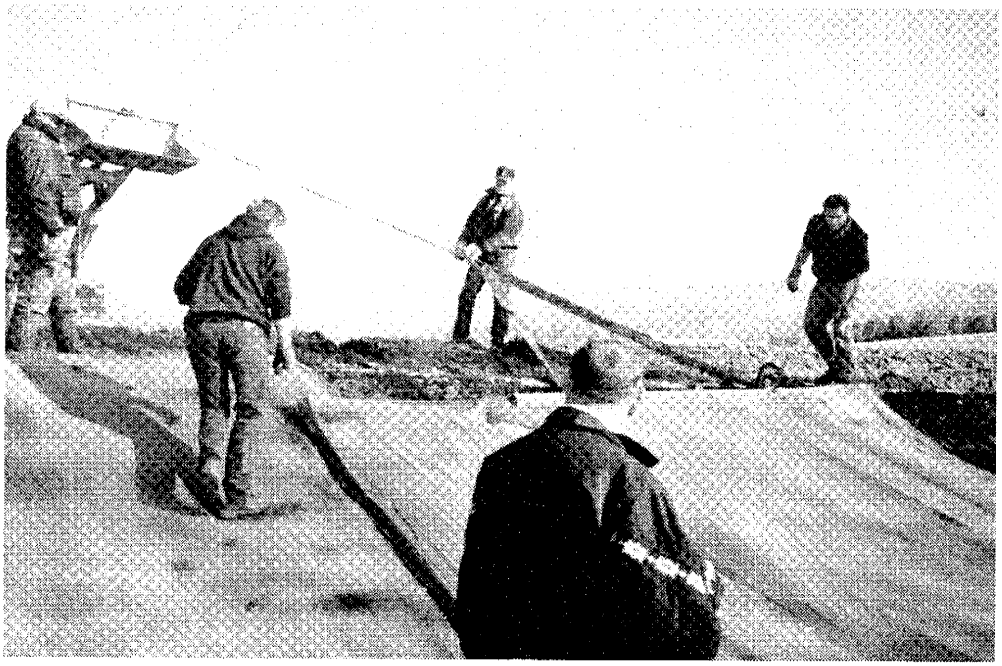
Ochoco Irrigation District – Test Section O-5
Exposed 160-mil Coletanche NTP 2 ES



Photograph 10.—District used 2 by 4s and clamps to grip the geomembrane.



Photograph 11.—Geomembrane is pulled off the roll and into the canal.



Photograph 12.—Small frontloader pulls the geomembrane up the far bank and into position.



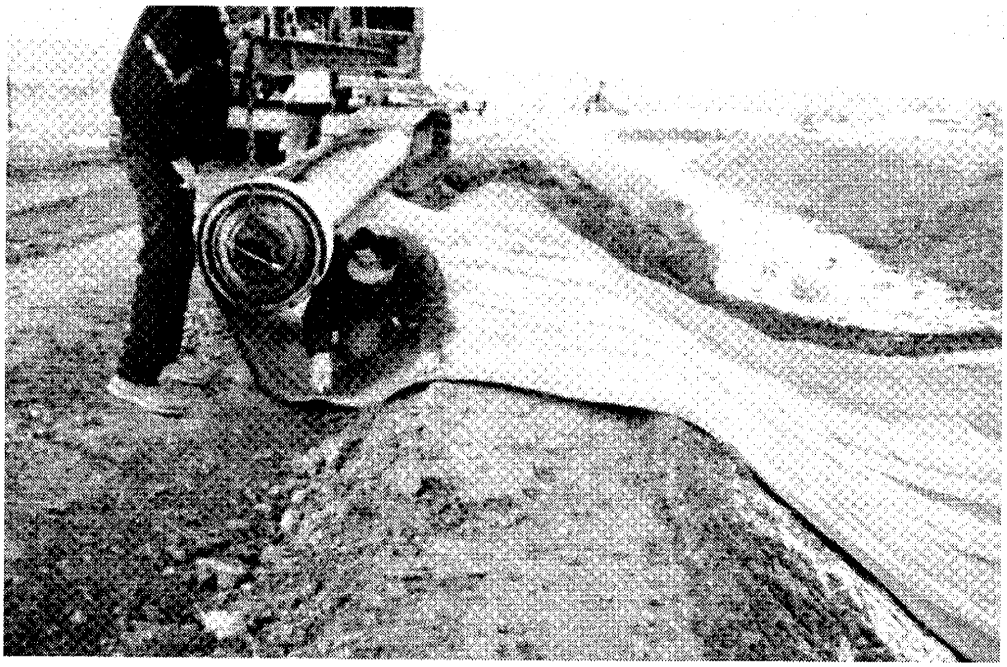
Photograph 13.—Geomembrane easily supports worker while suspended across the canal.



Photograph 14.—Trackhoe and front loader coordinate precise placement of the geomembrane liner.



Photograph 15.—Overview of liner placement.



Photograph 16.—After positioning, the liner is cut to length with little or no waste.



Photograph 17.—A propane torch is used to seam the geomembrane.

Ochoco Irrigation District – Test Section O-5
Exposed 160-mil Coletanche NTP 2 ES



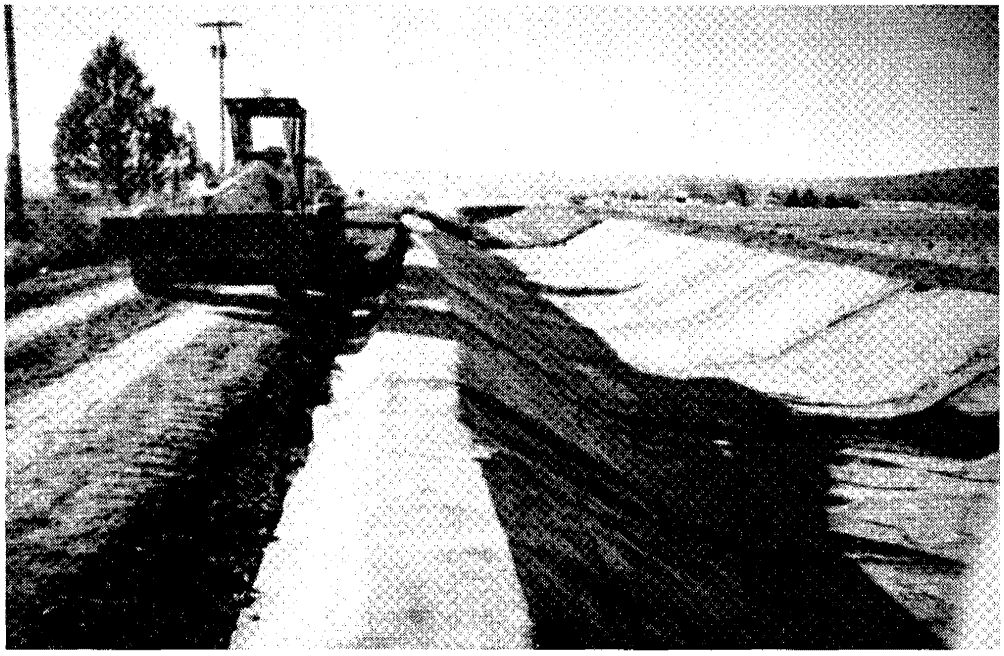
Photograph 18.—After heating with the torch, seams are pressed together with a paint roller.



Photograph 19.— Seamer places a large patch over a wrinkled seam caused by uneven subgrade.



Photograph 20.—Ultrasonic testing of the seam.

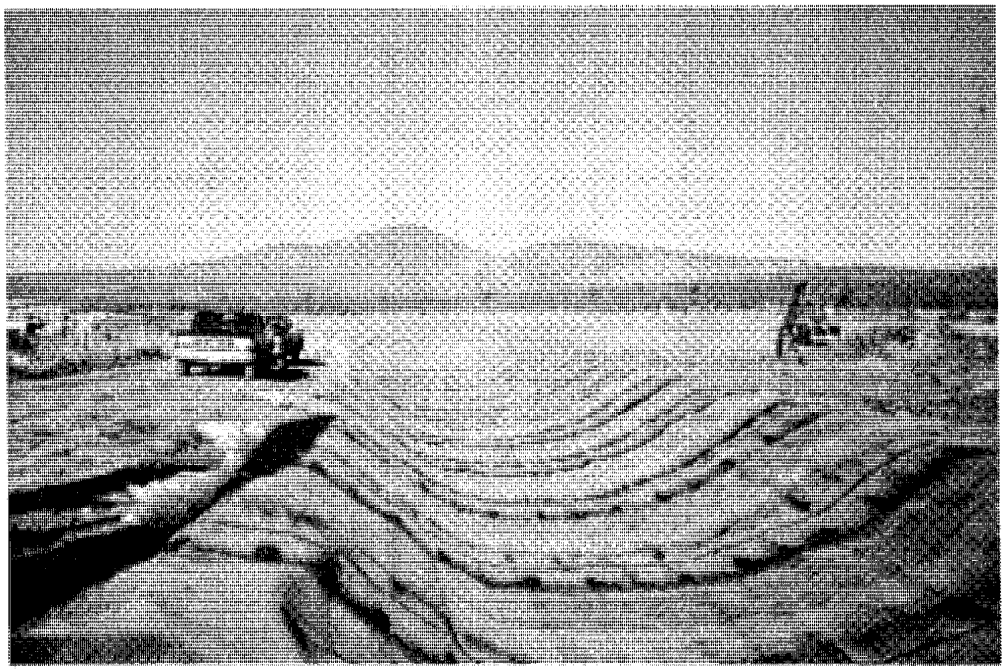


Photograph 21.—The grader backfills the V-notch anchor trench.

Ochoco Irrigation District – Test Section O-5
Exposed 160-mil Coletanche NTP 2 ES



Photograph 22.—The anchor trench has been backfilled up to the edge of the canal.



Photograph 23.—Finished Colas test section.

Test Section BU-1.—

Material:	1a = Exposed 60-mil White Textured HDPE with 10-oz Geotextile Cushion 1b = Exposed 60-mil White Textured HDPE
Date Installed:	April 2001
Location:	Buffalo Rapids Irrigation Project, near Glendive MT (figure 4) (4900 linear feet, 189,500 ft^2 geomembrane, 57,400 ft^2 geotextile)
Description:	The 60-mil textured HDPE geomembrane is coextruded with a white surface on one side and a black surface on the other. The geomembrane is installed with the white side up. Geotextile (where used) is a 10-oz needle-punched, nonwoven (Synthetic Industries 1071). Material data sheets are included in appendix A.
Prime Contractor:	Buffalo Rapids Irrigation Project
Material Supplier:	GSE Lining Technology Inc.
Surface Preparation:	The irrigation project performed extensive subgrade preparation by removing vegetation to 1 foot above the waterline, restoring the approximately 1½:1 to 2:1 side slopes, and cutting a 2-foot-wide bench for anchoring on each bank. The side slopes are approximately 1½:1 through the cut, and approximately 2:1 before and after the cut. The cost of subgrade preparation is estimated at \$0.26 per ft^2, based on the subgrade preparation costs on previous similar test sections. The finished canal prism measures 38 to 40 feet across, including the 1 to 2 feet of material buried in the anchor berm on each bank. The finished canal invert is 12 to 13 feet across, and the side slopes are 5 to 6 feet high. Water typically runs about 4 to 5 feet deep, and this section of canal typically carries about 200 cfs. Seepage is suspected to cause erosion on the face of a bluff over the Yellowstone River south of the canal. The downstream 1,300 feet of the test section contains cobbles and large rock and was previously lined with asphalt during the original construction in 1941. The irrigation project also improved the access road along the north side of the canal through the cut. These costs are not included in the cost estimates.
Construction:	An eight-man crew (including two machine operators) installed the geomembrane. The crew first rolled out the 15-foot-wide geotextile cushion in the road, and then pulled it into place in the canal invert. The HDPE geomembrane is manufactured in 22½-foot-wide rolls. The rolls were unrolled across the canal by a trackhoe operating in the canal invert. The geomembrane was temporarily secured with sandbags and 1-foot-long pins. Working from the access road, a second trackhoe then covered the anchor berm with 1 to 2 feet

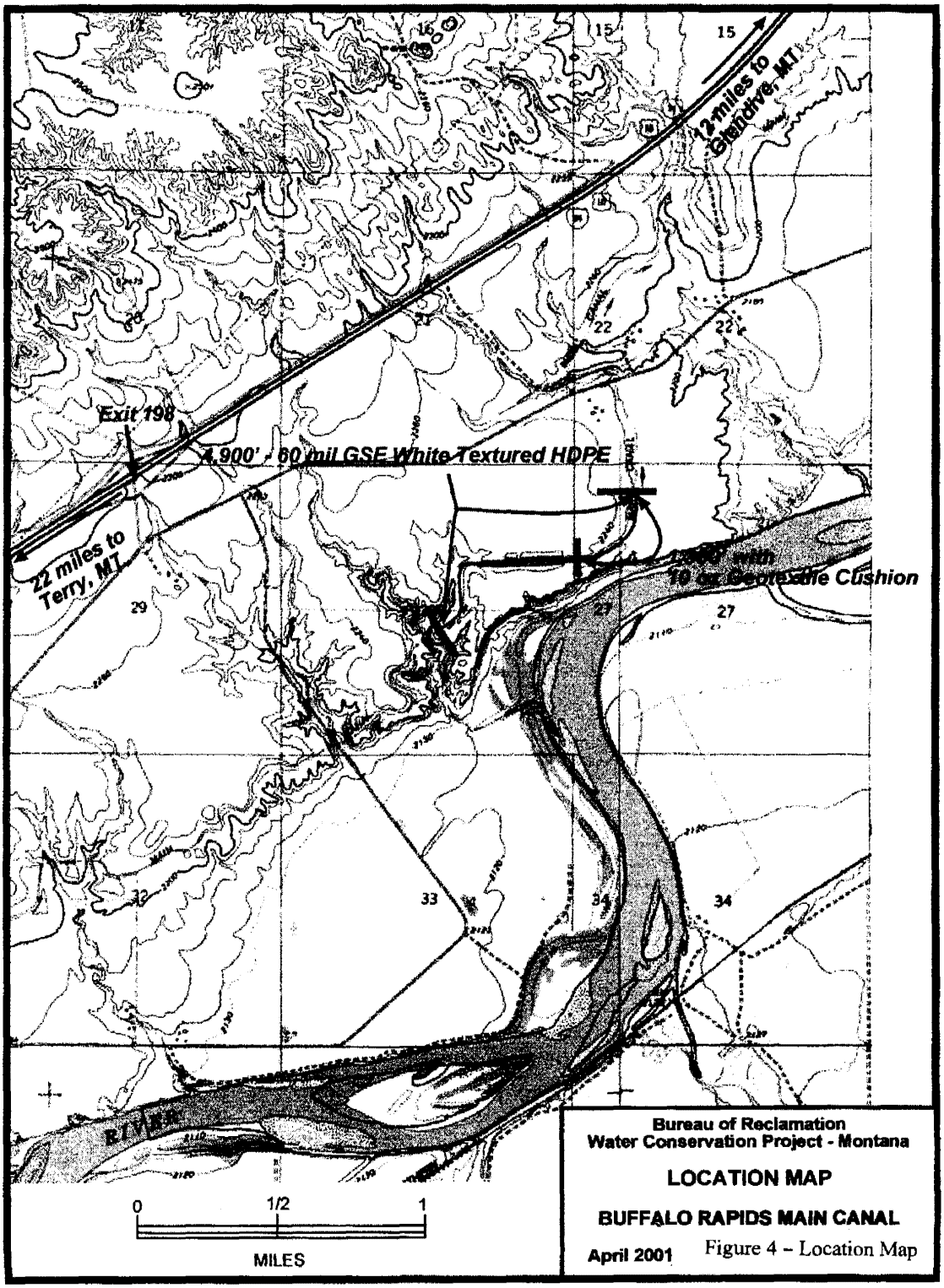


Figure 4 – Location Map

of cover soil and rock. The geomembrane panels were shingled downstream, overlapped 4 to 6 inches, and hot-wedge welded. Before seaming, the geomembrane was cleaned to remove any dirt and mud. GSE provided two men for the seaming operation.

The subgrade of the downstream 1,300 feet of the test section contains large numbers of rounded river rocks in the subgrade of up to 6 inches in diameter. The subgrade became less rocky in the upstream direction. Therefore, the lower 1,300 feet of the test section was covered with a 10-oz geotextile cushion. The cost estimates include both options.

Difficulties: The textured geomembrane snagged on the geotextile cushion. For future application, a smooth geomembrane is recommend when using a geotextile cushion. Also, problems were experienced removing the thick vegetation above the waterline. Heavy rains during installation caused problems with water in the canal invert. A pump and wet-vac were used to dry out the canal invert before seaming. The contractor used a rub sheet to keep the liner clean during seaming and to provide a cushion over vegetation at the top of the side slope.

Unit Cost Estimate: Exposed 60-mil white textured HDPE with 10-oz Geotextile Cushion = $1.22 per ft^2.
($0.60 geomembrane + 0.10 Geotextile cushion + 0.26 surface prep + 0.10 installation +17% OH and profit)

Exposed 60-mil white textured HDPE = $1.12 per ft^2.
($0.60 geomembrane + 0.26 surface prep + 0.10 installation +17% OH and profit)

Advantages: The white surface decreases surface temperatures and thermal expansion. The white on black surface also made it very easy to see any defects or tears in the geomembrane surface. The project can perform minor repairs using a $500 hot air welder.

Disadvantages: Lots of seaming was required because of the 22-foot roll width. Unrolling two rolls of geomembrane down the canal would reduce the amount of seaming, but would use about 10 percent more material. The Buffalo Rapids Project should consider purchasing a $500 hot air welder to perform minor repairs.

Photographs: 1 through 26

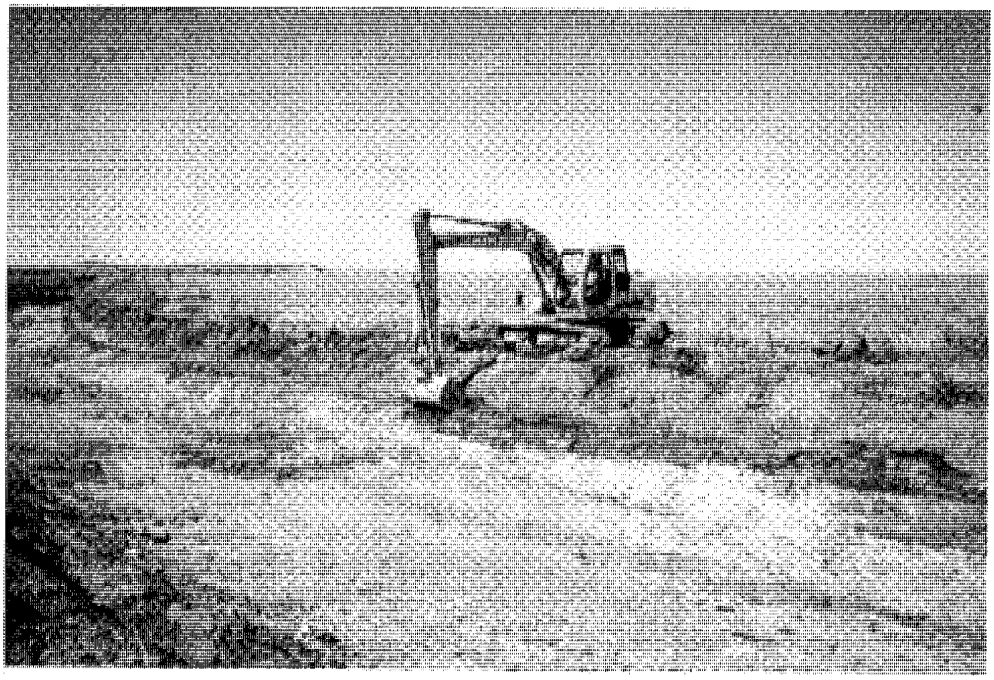
Buffalo Rapids Irrigation Project – Test Section BR-1
Exposed 60-mil White Textured HDPE with 10-oz Geotextile Cushion



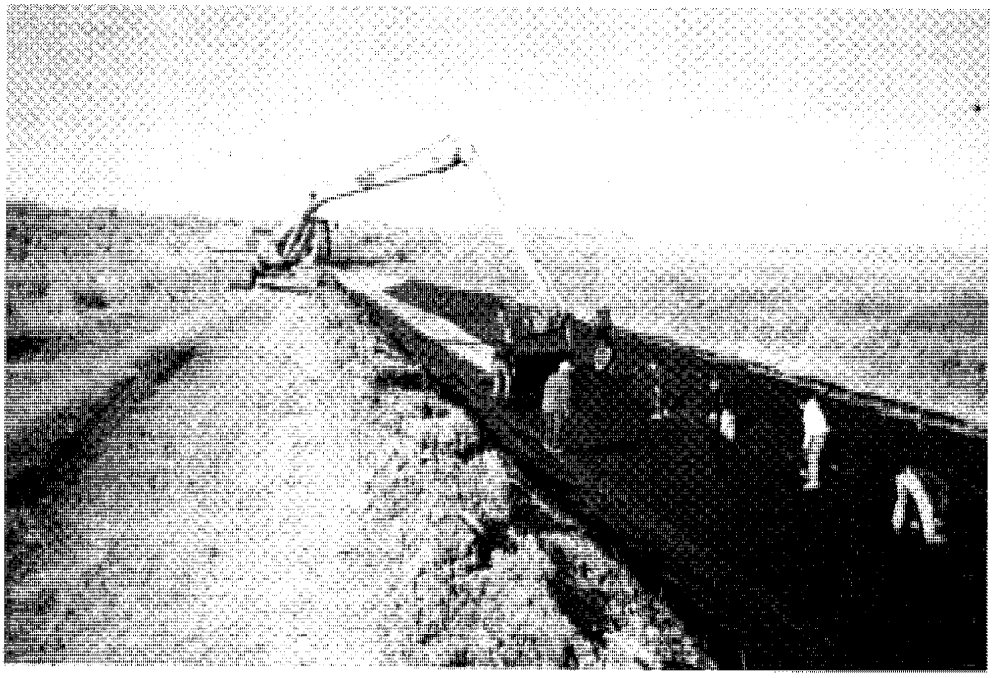
Photograph 1.—Canal subgrade where geotextile cushion will be used. Small pieces of the old asphalt lining can be seen in the right foreground.



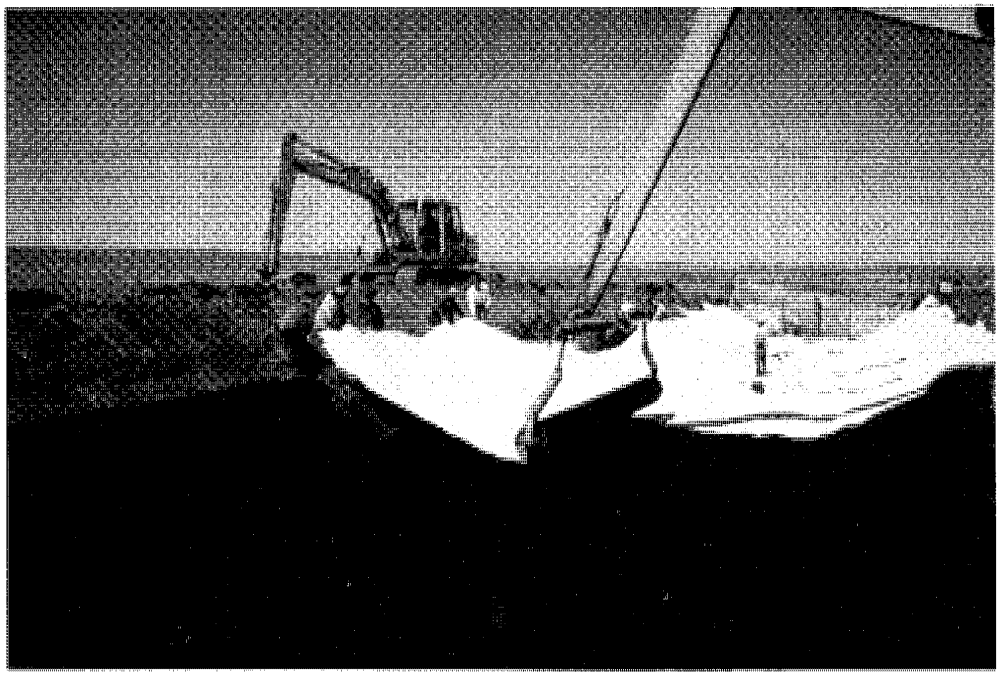
Photograph 2.—Canal subgrade through the "Deep Cut." Large dirt clods in the invert rolled down the embankment during road improvement.



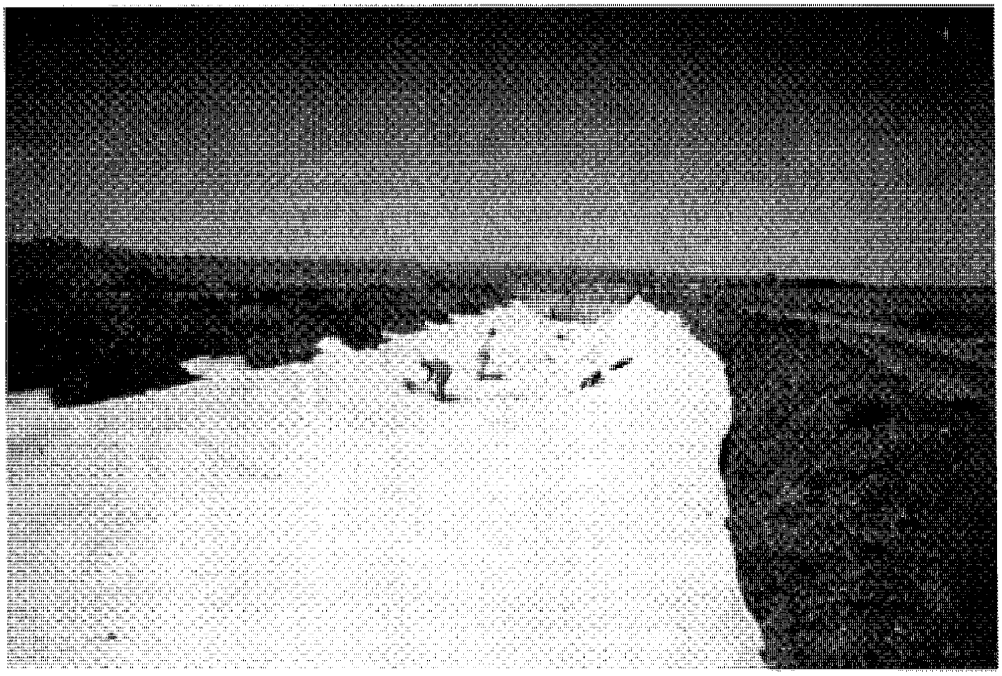
Photograph 3.—Backhoe excavates the 2-foot-wide anchor berm located 1 foot above the water line.



Photograph 4.—Geotextile cushion was placed over rocky subgrade in the downstream 1,300 feet of the test section. The 10-oz geotextile is placed lengthwise down the canal.



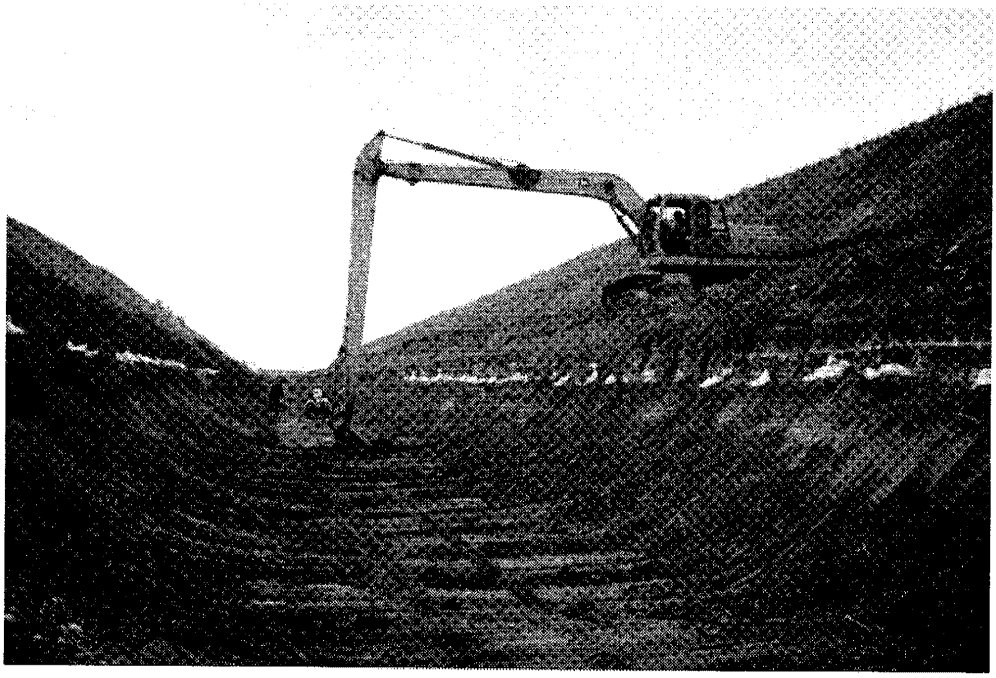
Photograph 5.—Starting at the downstream check structure, the geomembrane is installed perpendicular to the flow in the canal and overlapped downstream.



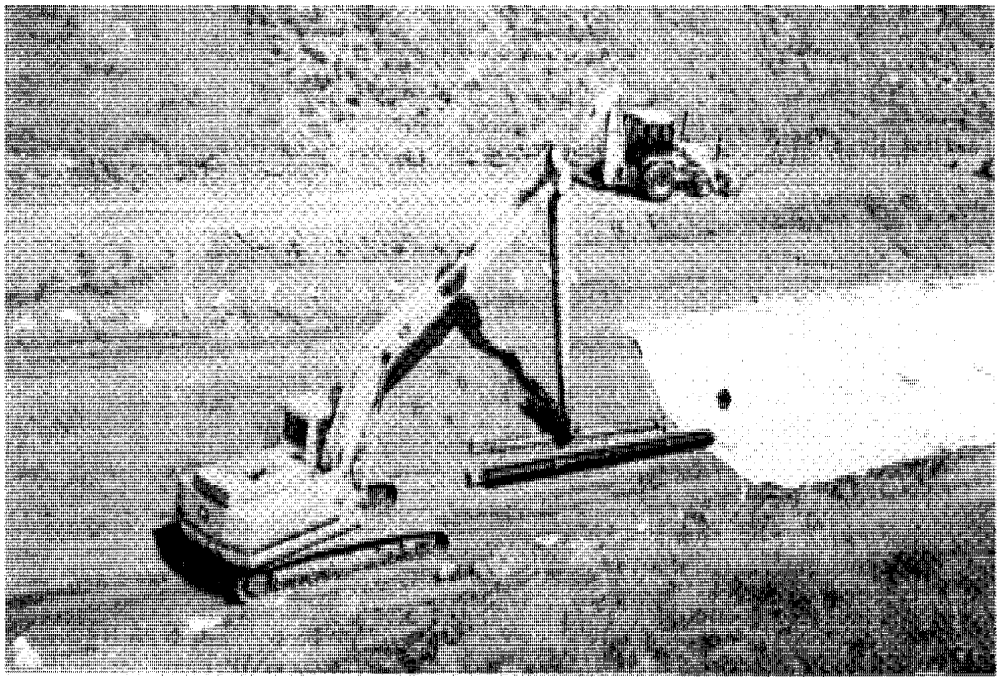
Photograph 6.—View of nearly complete installation in the downstream section.



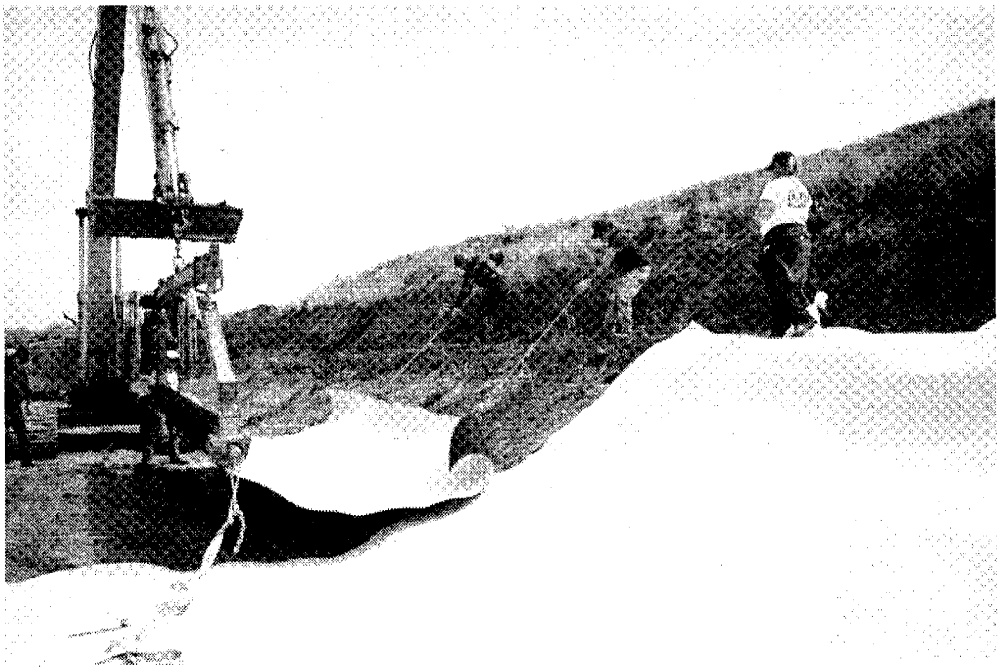
Photograph 7.—When the wind came up, sandbags were needed to temporarily secure the geomembrane. Laborers shown filling the sandbags.



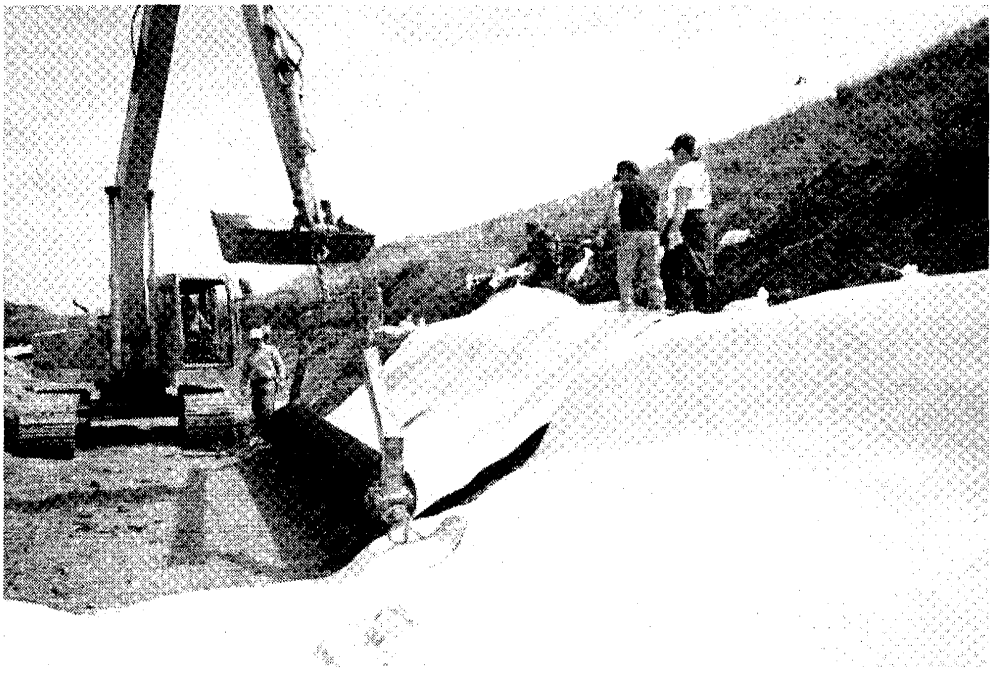
Photograph 8.—Large Trackhoe performs final trimming on the subgrade. Note the sandbags in position on the anchor bench.



Photograph 9.—Trackhoe operating in the canal invert to unroll geomembrane across the canal.



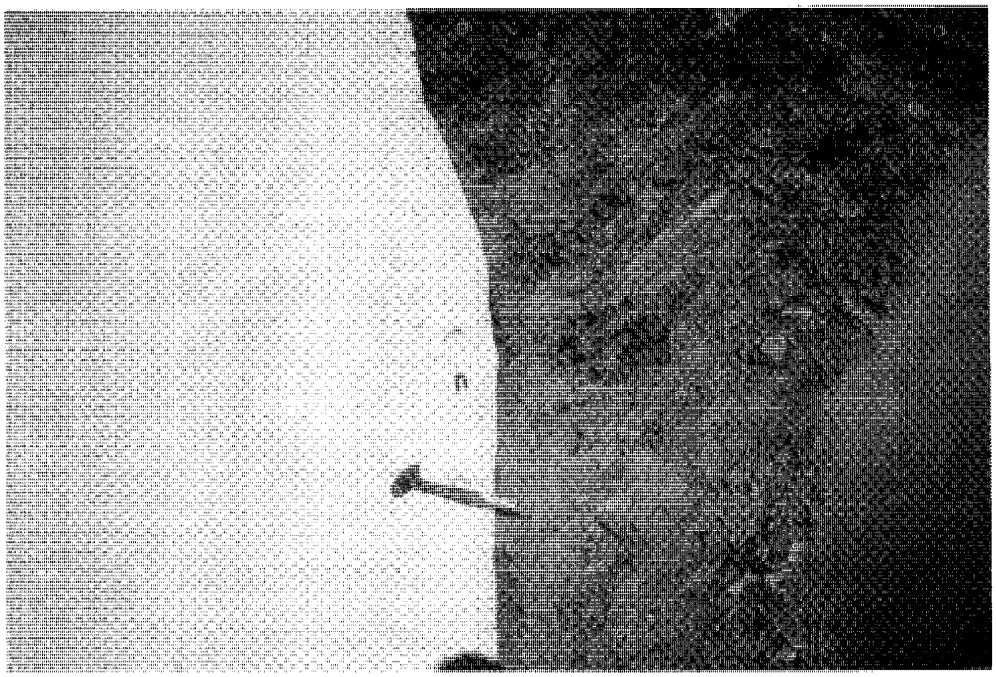
Photograph 10.—Crew assists in unrolling and placing of the geomembrane.



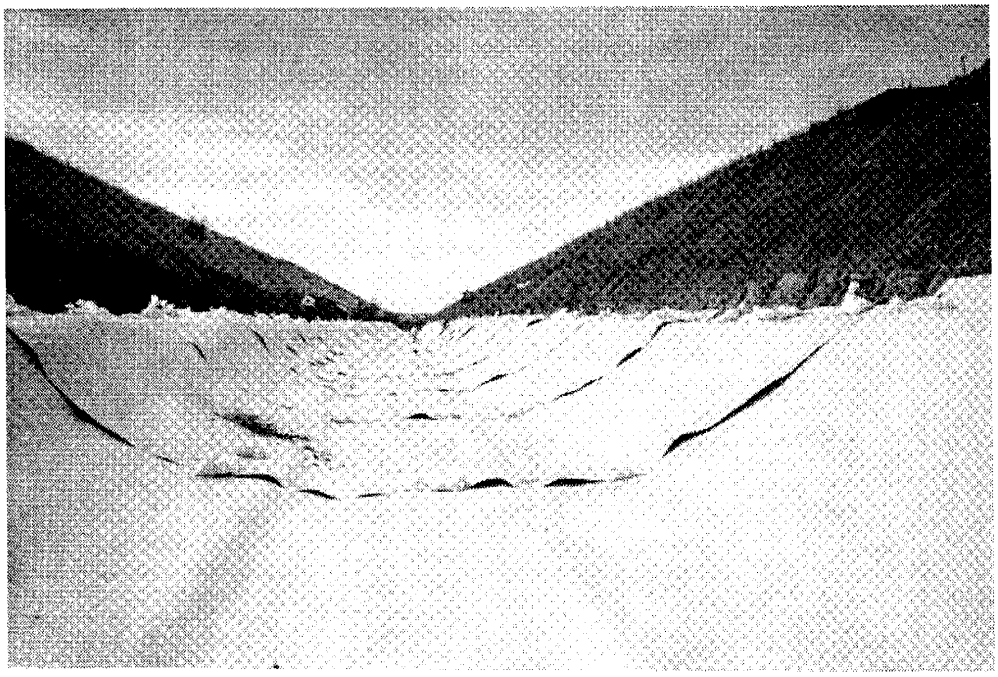
Photograph 11.—Trackhoe unrolls geomembrane while sandbags and 1-foot tell pins hold it in place on the anchor bench.



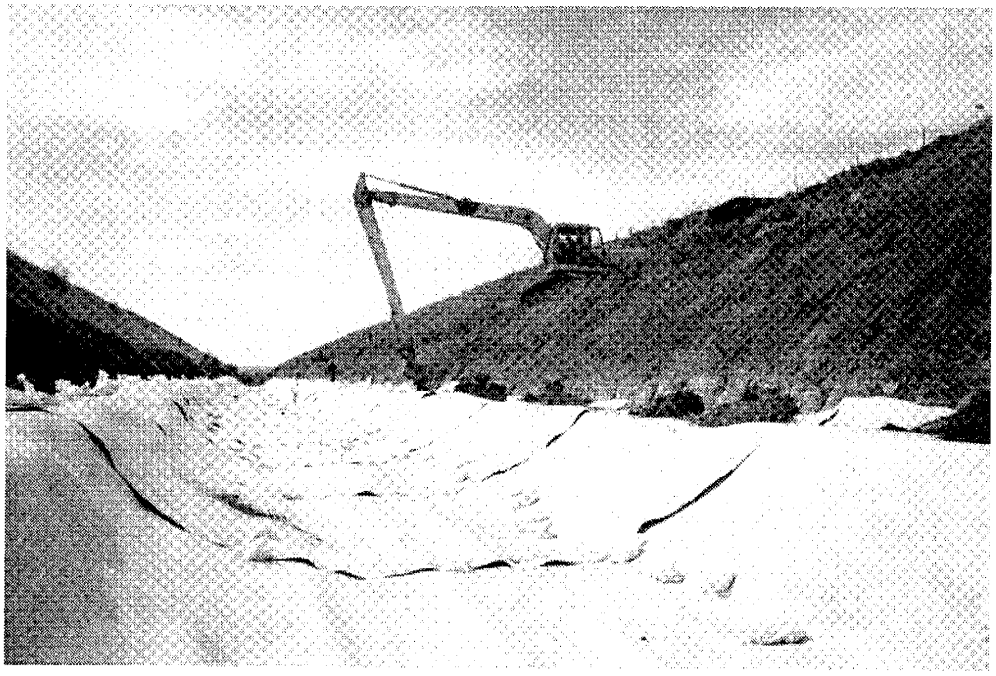
Photograph 12.—Trackhoe unrolls geomembrane up the other bank, where it will be cut to size and secured to the anchor bench.



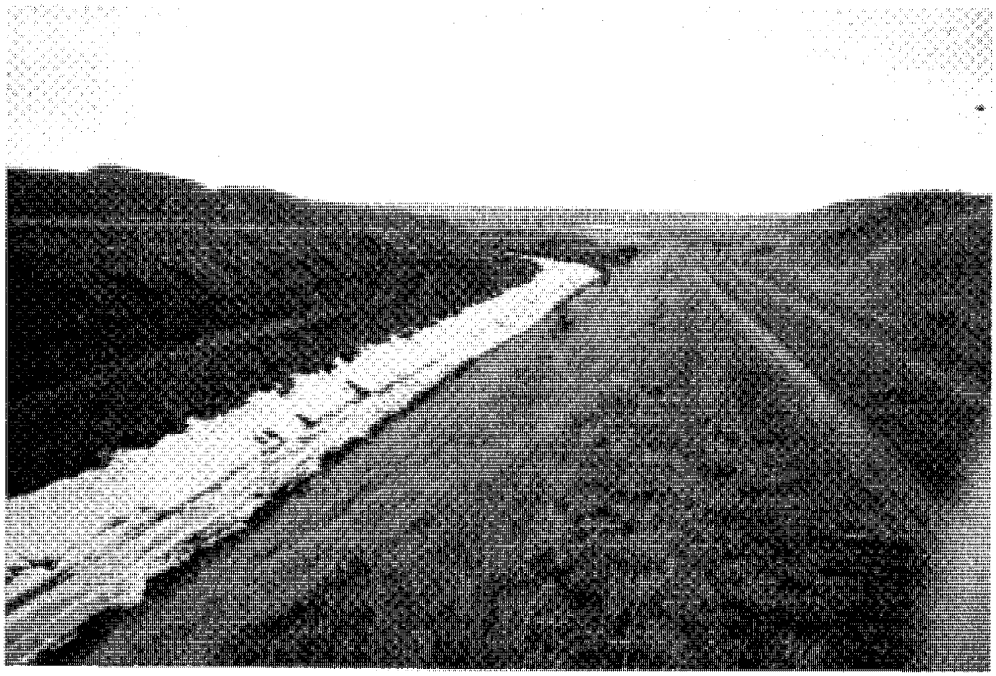
Photograph 13.—Steel pin has been driven into the anchor bench to secure the Geomembrane.



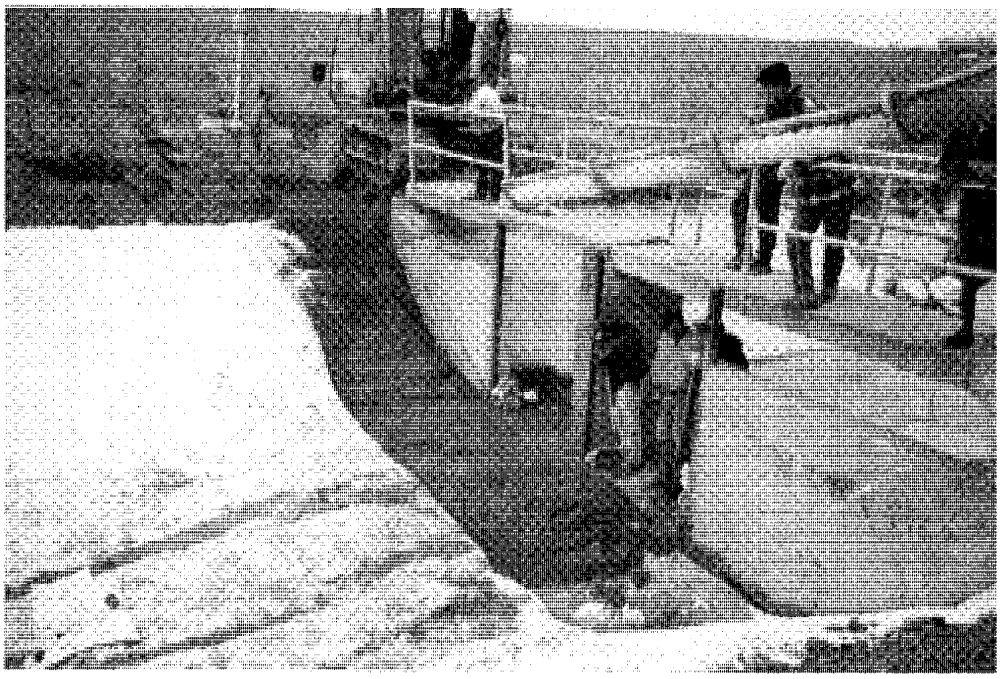
Photograph 14.—Several panels have been installed across the canal and temporarily secured with sandbags. Geomembrane panels still need to be seamed, and the anchor bench needs to be backfilled.



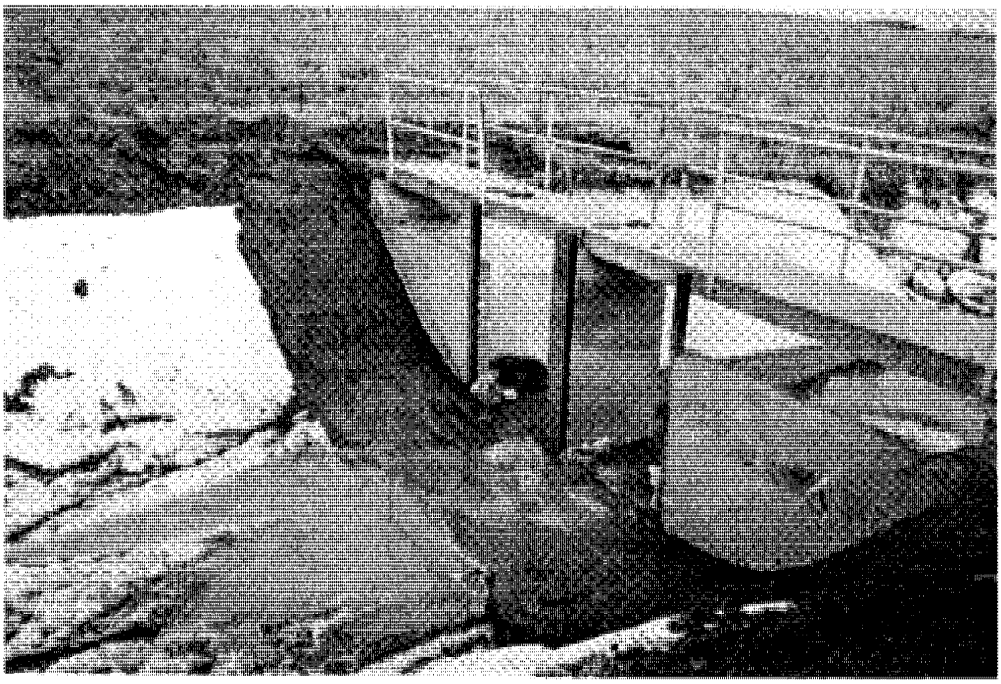
Photograph 15.—Sandbags are removed and moved upstream as the trackhoe backfills portions of the anchor bench. Backfill is not placed in the immediate vicinity of areas to be seamed.



Photograph 16.—View from the top of the "Deep Cut" looking downstream.



Photograph 17.—Cut-off trench at downstream check structure is filled with concrete and measures about 5 feet wide and 2 feet deep.



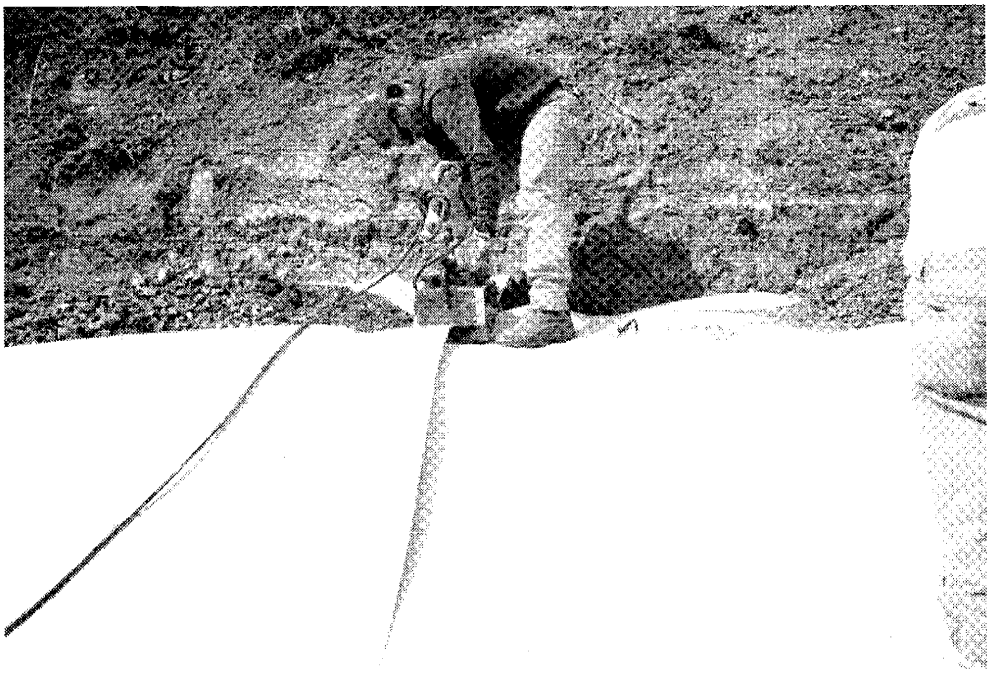
Photograph 18.—Completed downstream cut-off trench.



Photograph 19.—Heavy rains deposited water in the canal invert. A small pump is used to remove water from the area of the seam.



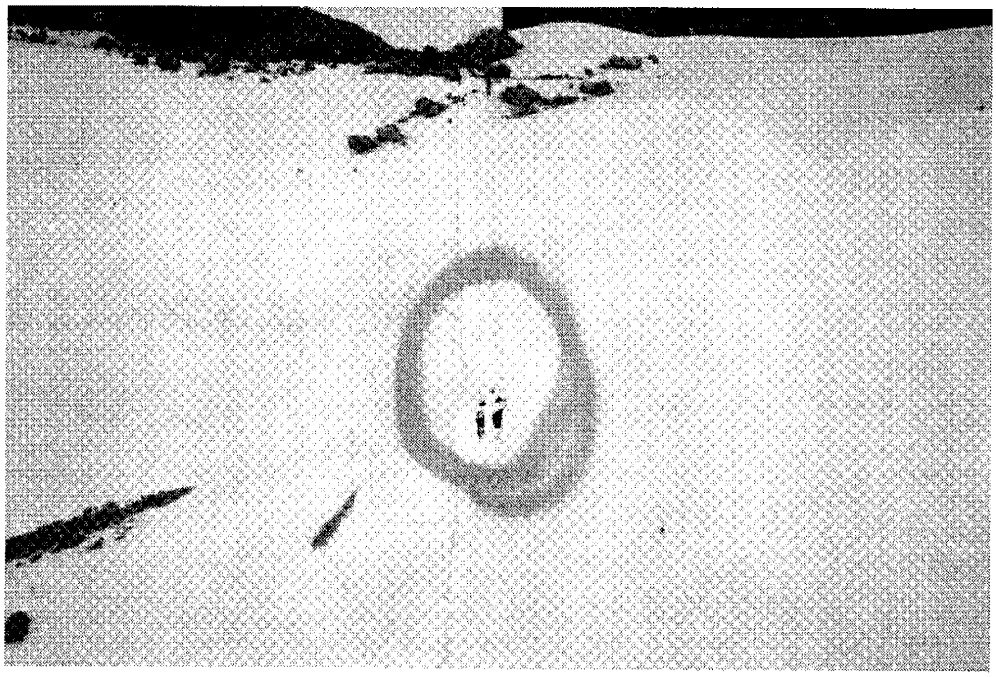
Photograph 20.—Standing water and mud had to be removed from the liner before seaming.



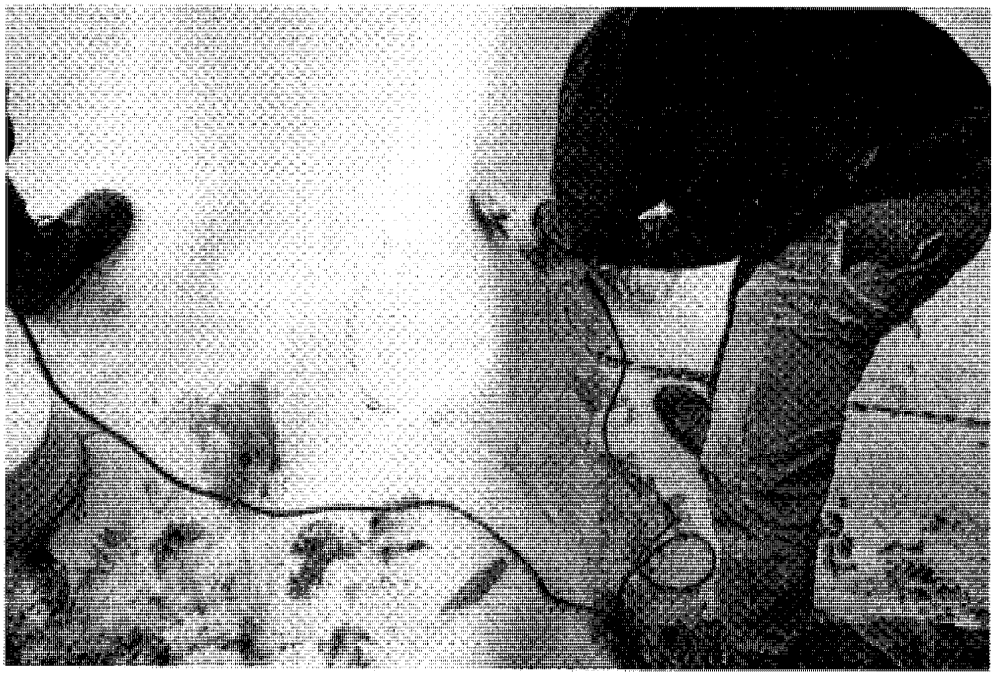
Photograph 21.—Self-propelled dual-wedge welder used for seaming.



Photograph 22.—Welding technician applies pressure behind the wedge welder to remove small wrinkles in front of the wedge.



Photograph 23.—Damage caused by wedge welder that needs to be repaired.



Photograph 24.—After tacking the patch in place with a hot-air gun, edges of the patch are ground off.



Photograph 25.—Welding Technician uses extrusion welder to apply patches to the geomembrane. Extrustion rod is white to match the liner.



Photograph 26.—Completed test section. All seams have been welded, and anchor bench has been backfilled.

Test Section BI-I.—

Material:	Exposed 20-mil EVA with 8-oz geotextile bonded to both sides
Date Installed:	October 2001
Location:	Bitter Root Irrigation District, near Hamilton MT (figure 5) (900 linear feet, 4,500 square feet)
Description:	The membrane is GeoComp Canal^3 (Canal-Cubed) geocomposite. It is composed of a gray 8-oz geotextile cushion; 20-mil EVA; and a black, 8-oz, geotextile cover. Both polyester geotextiles and the EVA geomembrane are made from recycled polymer. The geomembrane composite is installed with the black geotextile facing up for UV protection. Material data sheets are included in appendix A. GeoComp also supplied some 12-30-12 geocomposite for this job. The 12-30-12 is composed of a black 12-oz geotextile cushion, 30-mil EVA membrane, and a black 12-oz geotextile UV cover. The 12-30-12 costs $0.53 per square foot, and is probably better suited for exposed applications.
Prime Contractor:	Bitter Root Irrigation District
Material Supplier:	GeoComp Inc.
Surface Preparation:	The irrigation district performed extensive subgrade preparation by removing vegetation to 1 foot above the waterline, removing large rocks, restoring the approximately 1½:1 side slopes, and cutting a 2- to 3-foot-wide bench for anchoring on each bank. The cost of subgrade preparation is estimated at $0.26 per ft^2, based on the subgrade preparation costs of previous similar test sections. The finished canal prism measures 40 to 45 feet across. The invert is 12- to 15-feet and 7- to 8-ft deep. This section of canal typically carries about 300 cfs and runs about 6 feet deep. The finished subgrade is quite rocky, with rounded cobbles up to 6 inches in diameter. Seepage from the canal has been flooding fields and a house located immediately to the north of the canal. The only access road is on the north side of the canal.
Construction:	The geomembrane was provided in 24-foot-wide rolls that are 275 feet long. A four to six man crew (including a trackhoe operator) installed the geomembrane. Because the canal was accessible only from one side, the geomembrane was unrolled across the canal by a trackhoe operating in the canal invert. After the geomembrane panel was cut from the roll to fit to the canal width (45 to 50 ft), the trackhoe would unhook the lifting bar and use its bucket to place cover material on the far anchor berm. The trackhoe would then back up 24 feet, re-attach to the lifting bar, and unroll the next panel. Panels were shingled downstream and overlapped a minimum of 1 foot. Overlaps of 3 to 4 feet were typical because of the uneven subgrade and bends in canal alignment. At the end of each day, the trackhoe would drive out of the canal and backfill the near anchor berm. Lining started at the bridge and proceeded upstream. The District placed and seamed about 900 linear feet of

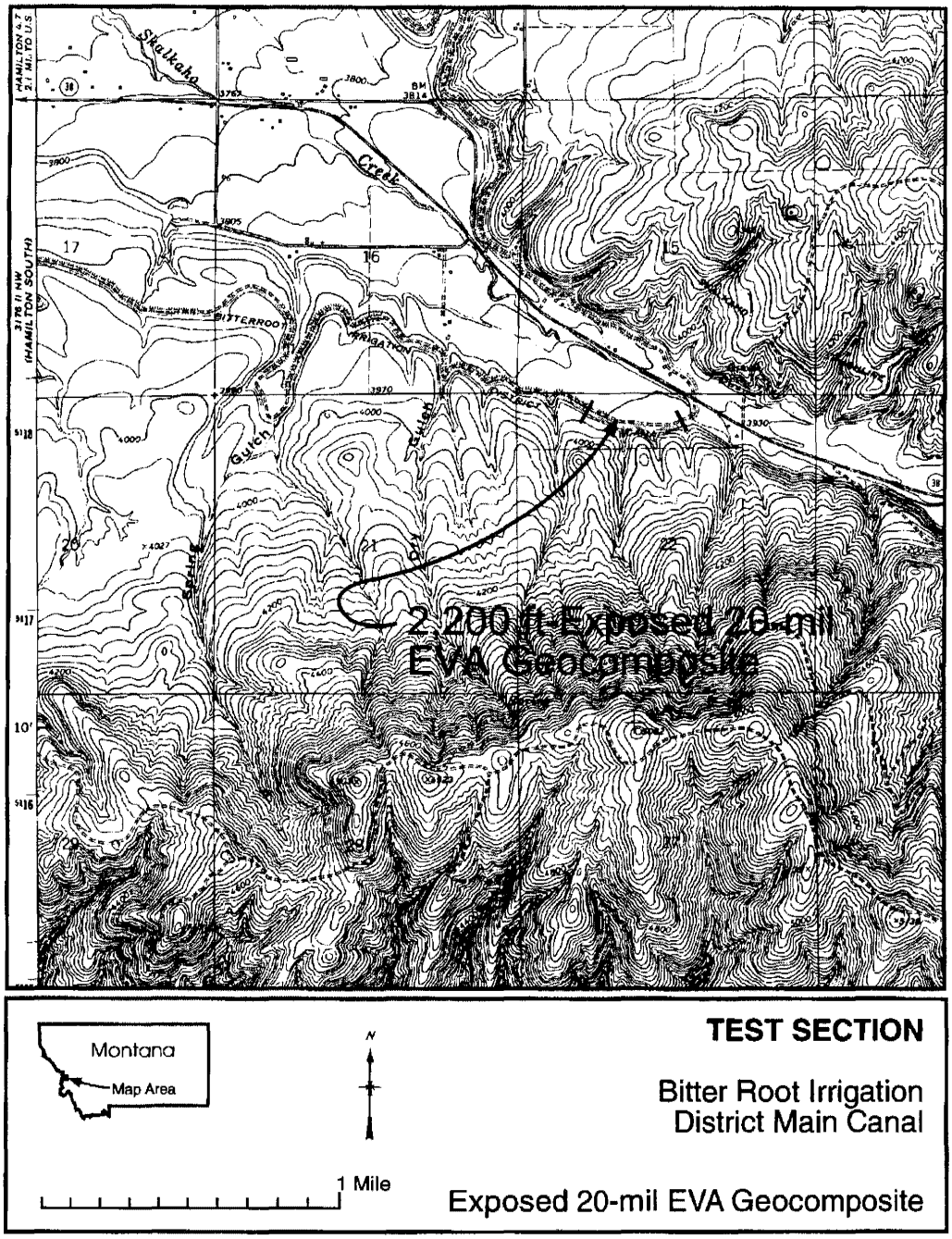


Figure 5.—Location map.

geomembrane liner in 3 days. The geomembrane was placed into a 2-foot-wide cut-off trench at the upstream and downstream ends. Another 1,300-foot section downstream from the bridge was too wet for lining at this time. As weather permitted, this downstream section was lined during the winter of 2001-2002, bringing the total test section to 2,100 linear feet.

Seaming was performed by a one to four man crew using an air-powered hot-glue gun provided by the geomembrane manufacturer. The hot-glue gun consisted of an air compressor, an air accumulator chamber, and the hot-glue gun. A generator powered the air compressor and the hot-glue gun. Glue was provided in hockey-puck-sized pellets. The pucks were loaded into a supply chamber and heated to 450 °F. The gun extruded a 1/4- to ½-inch bead of hot glue into the seam. The seam was pressed together and held closed for several minutes to allow the hot glue to cool and set. Occasional geomembrane wrinkles and fishmouths were simply folded over and glued down. Inspection of the seams found a few unbonded areas (typically 6 to 12 inches long) where the seam was not pressed (held) together long enough for the glue to cool and set.

Difficulties: Seaming was quite slow, and the seams were inconsistent (unbonded areas) and relatively weak. The geomembrane manufacturer has a larger gun that places a 1-inch wide bead that would be more suitable for this material. The district switched over to hot roofing tar later in the week. The tar was supplied in a 100-gallon kettle. Hot-tar seaming was more labor intensive and relatively slow because of the time needed for the hot tar to cool and set. A hot-air welder may be another alternative for seaming this material.

Unit Cost Estimate: Exposed 20-mil EVA-geotextile geocomposite = \$0.83 per ft^2 (\$0.35 geocomposite + 0.26 surface prep + 0.10 installation +17% OH and profit).

Advantages: Installation was simplified by providing the geotextile cushion, EVA geomembrane, and geotextile cover in a single geocomposite.

Disadvantages: Lots of seaming was required because of the 24-ft roll width. The seaming crew had trouble keeping pace with the installation crew.

Photographs: 1 through 24

Bitter Root Irrigation District – Test Section BI-1
Exposed 20-mil EVA with 8-oz Geotextile Bonded to Both Sides

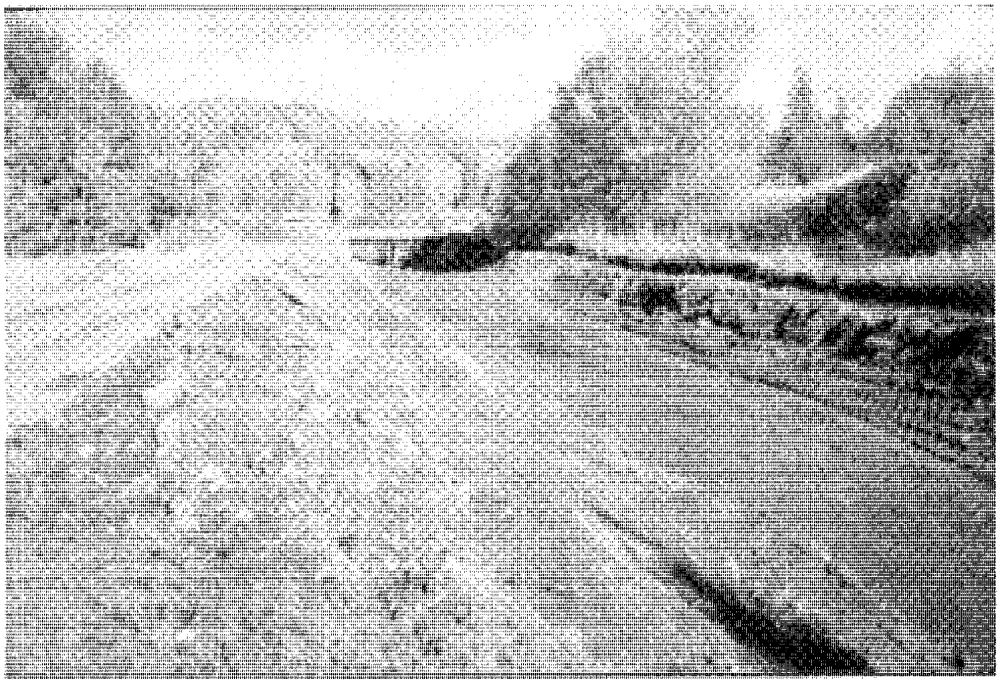
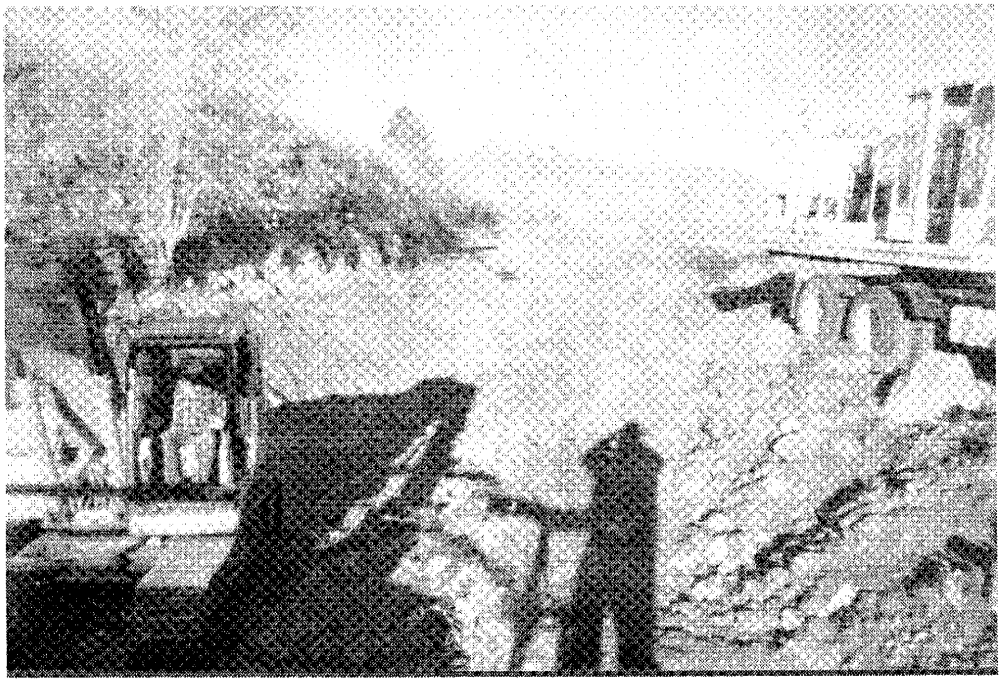


Photo 1.—The District performed extensive subgrade preparation by removing vegetation to 1 foot above the waterline, restoring the 1½:1 side slopes, and cutting a 2- to 3-foot anchor berm on each bank. The downstream section was too wet and was not lined at the time of the photograph.

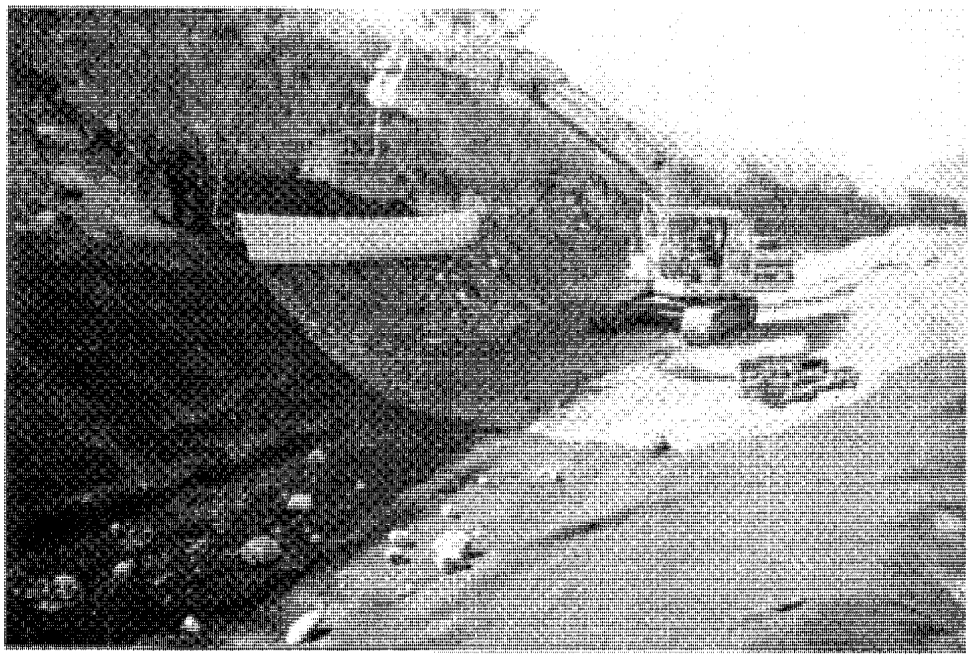


Photograph 2.—Upstream section ready for installation of lining.

Bitter Root Irrigation District – Test Section BI-1
Exposed 20-mil EVA with 8-oz Geotextile Bonded to Both Sides

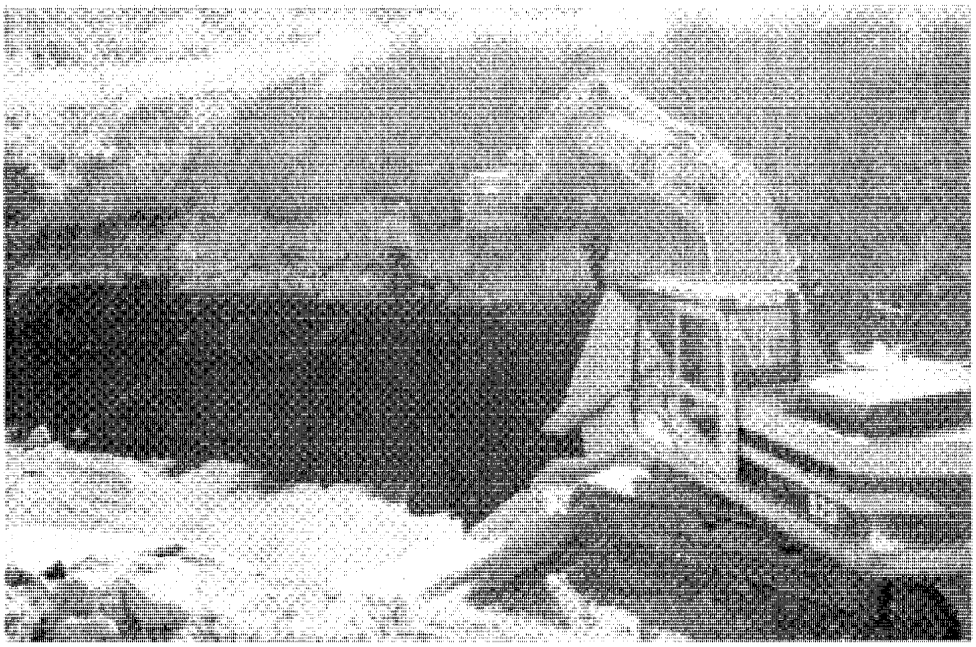


Photograph 3.—The prepared subgrade has large cobbles of up to 6 inches in diameter.

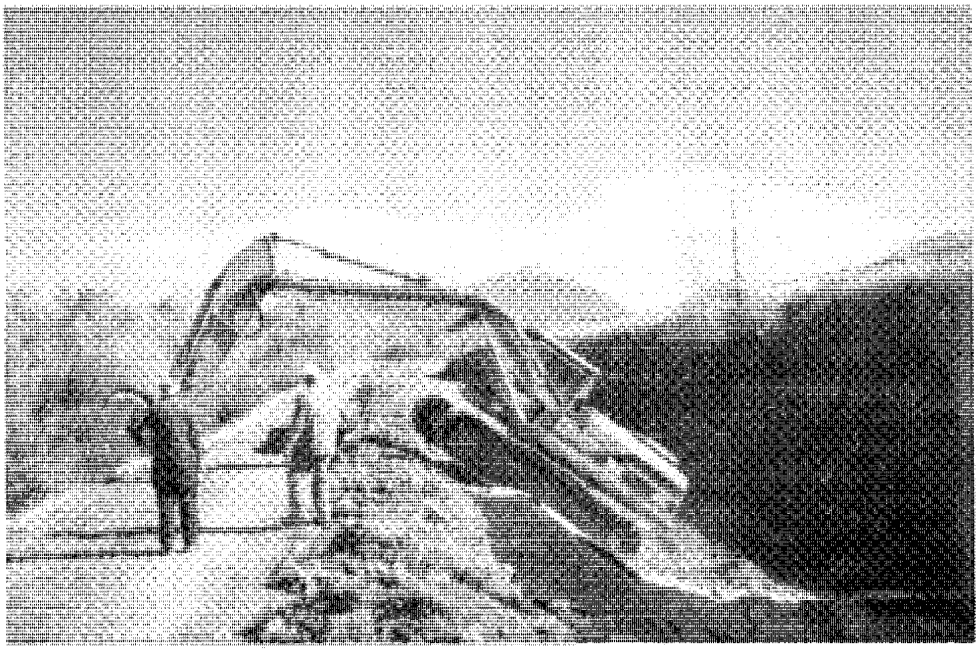


Photograph 4.—Trackhoe operating in the canal invert using a lifting bar to unroll geomembrane across the canal.

Bitter Root Irrigation District – Test Section BI-1
Exposed 20-mil EVA with 8-oz Geotextile Bonded to Both Sides



Photograph 5.—Trackhoe pulls down the far bank to cover geomembrane in the anchor berm.

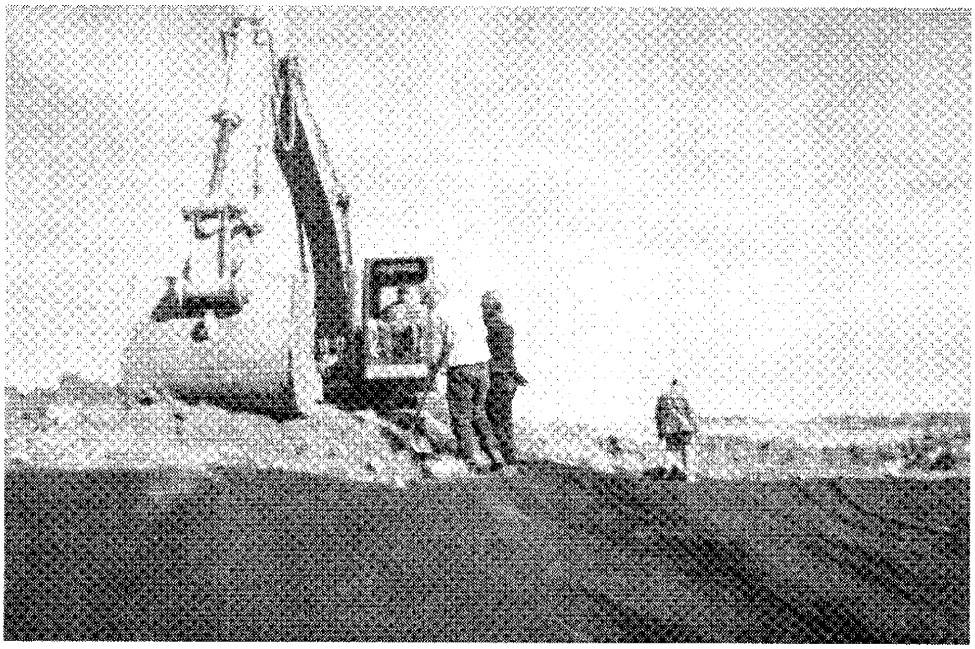


Photograph 6.—At the end of the day, the trackhoe drives up the side slope and out of the canal.

Bitter Root Irrigation District – Test Section BI-1
Exposed 20-mil EVA with 8-oz Geotextile Bonded to Both Sides



Photograph 7.—Trackhoe prepares to backfill the near anchor berm.

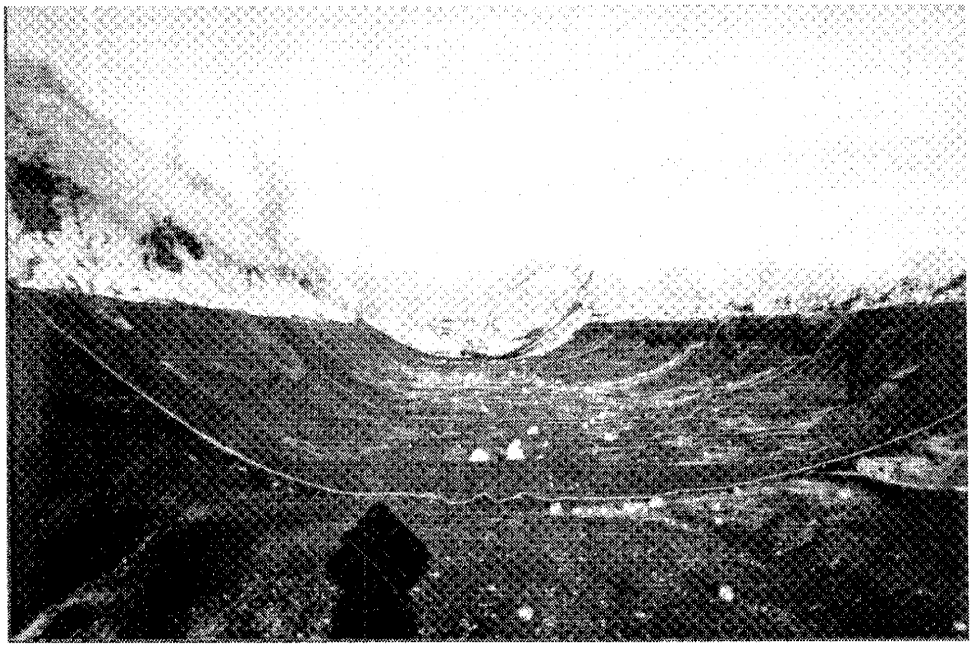


Photograph 8.—Laborers help backfill the near anchor berm.

Bitter Root Irrigation District – Test Section BI-1
Exposed 20-mil EVA with 8-oz Geotextile Bonded to Both Sides

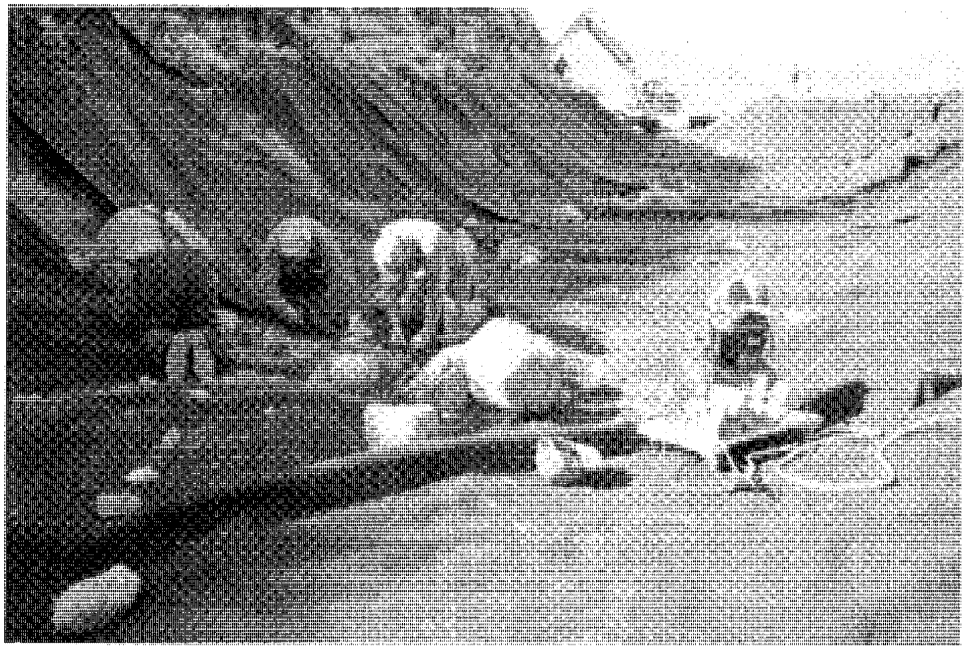


Photograph 9.—Backfill on near anchor berm is complete.

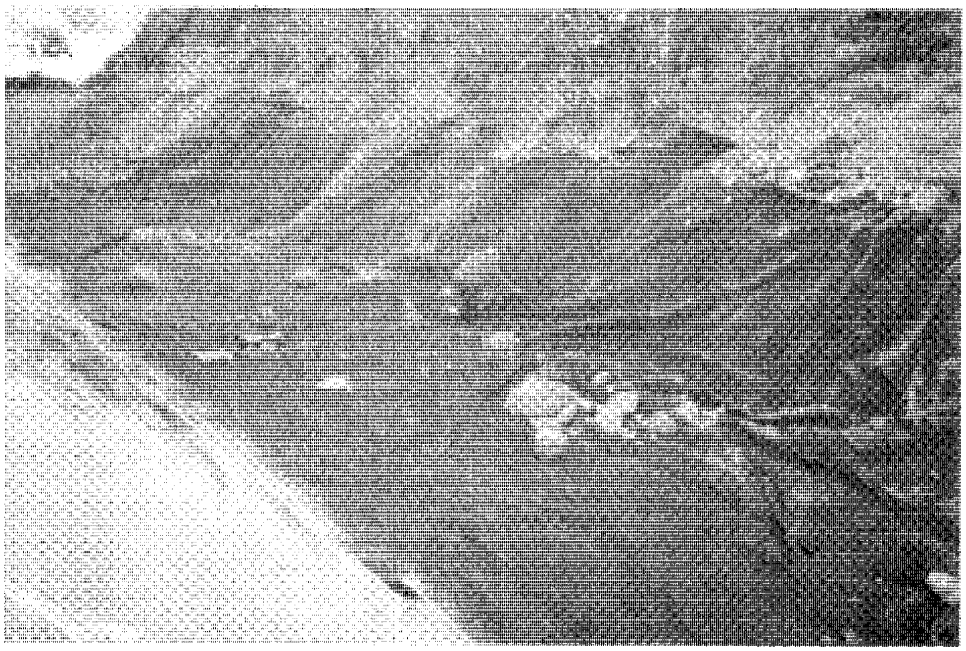


Photograph 10.—Overlapped seams are ready to be sealed. The trackhoe continues to lay geomembrane in the background.

Bitter Root Irrigation District – Test Section BI-1
Exposed 20-mil EVA with 8-oz Geotextile Bonded to Both Sides



Photograph 11.—Three-man crew removes dirt from the seam and seals it with hot glue. Seams need to be held shut until the hot glue cools and sets.

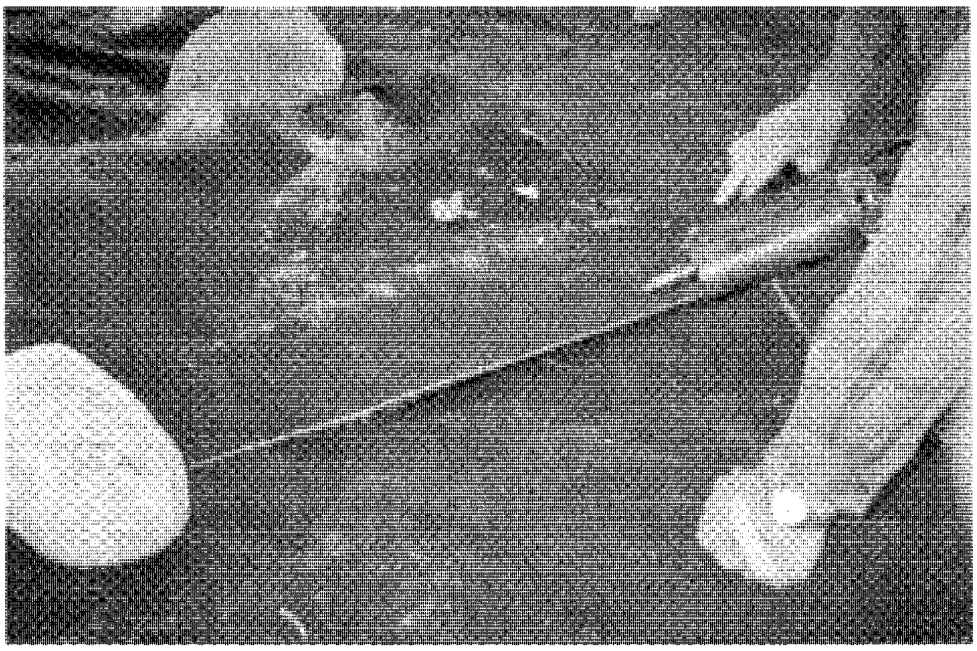


Photograph 12.—Seaming continues.

Bitter Root Irrigation District – Test Section BI-1
Exposed 20-mil EVA with 8-oz Geotextile Bonded to Both Sides

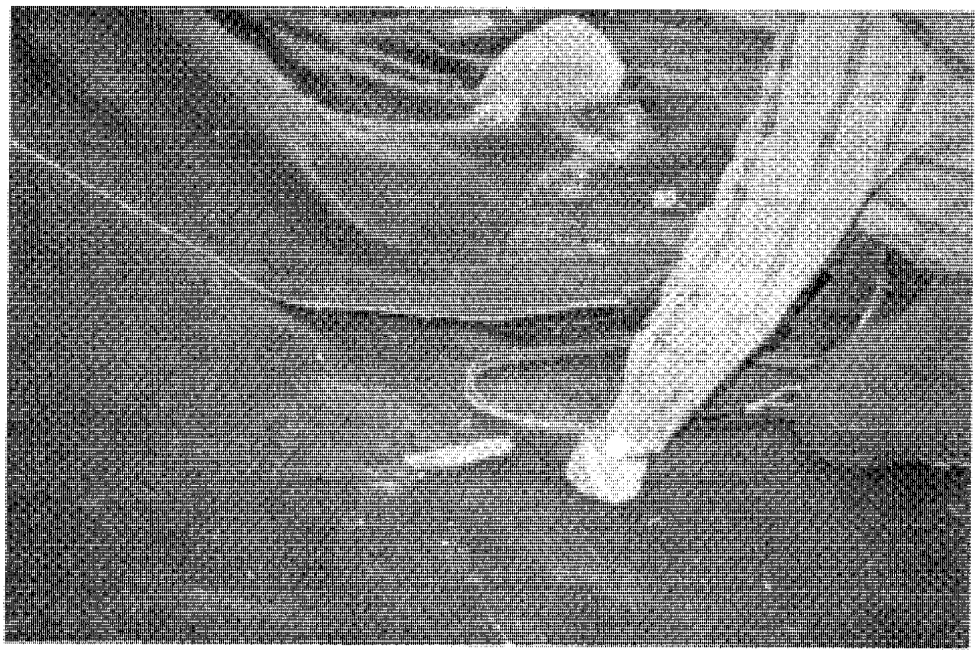


Photograph 13.—Closeup of the industrial hot-glue machine.



Photograph 14.—Closeup of seam with hot glue. Rock is placed on the seam to hold it together until the hot glue cools and sets.

Bitter Root Irrigation District – Test Section BI-1
Exposed 20-mil EVA with 8-oz Geotextile Bonded to Both Sides

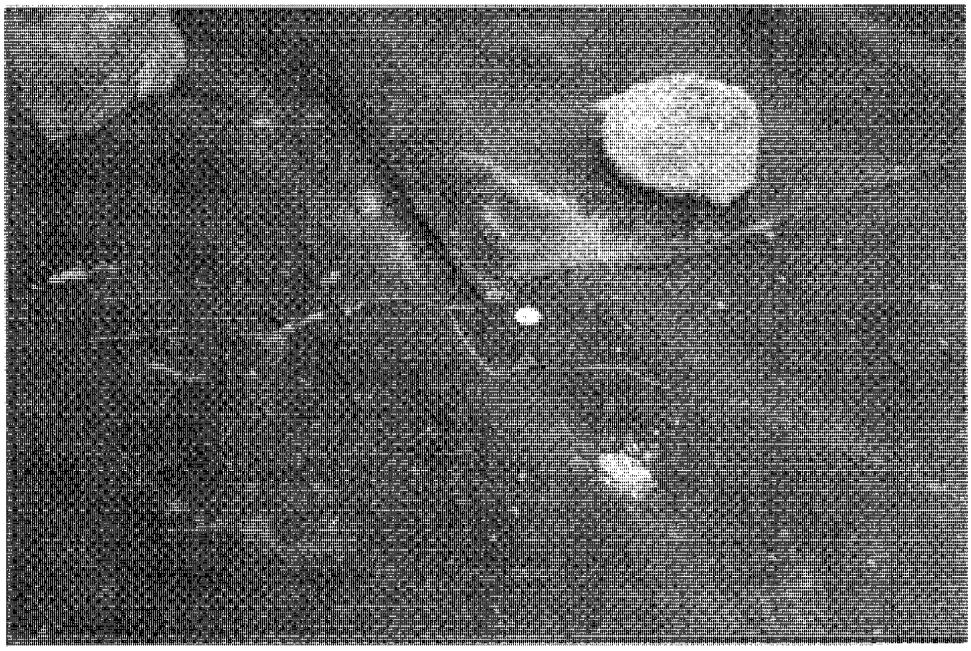


Photograph 15.—Hot glue is extruded into the seam in a ½-inch bead.

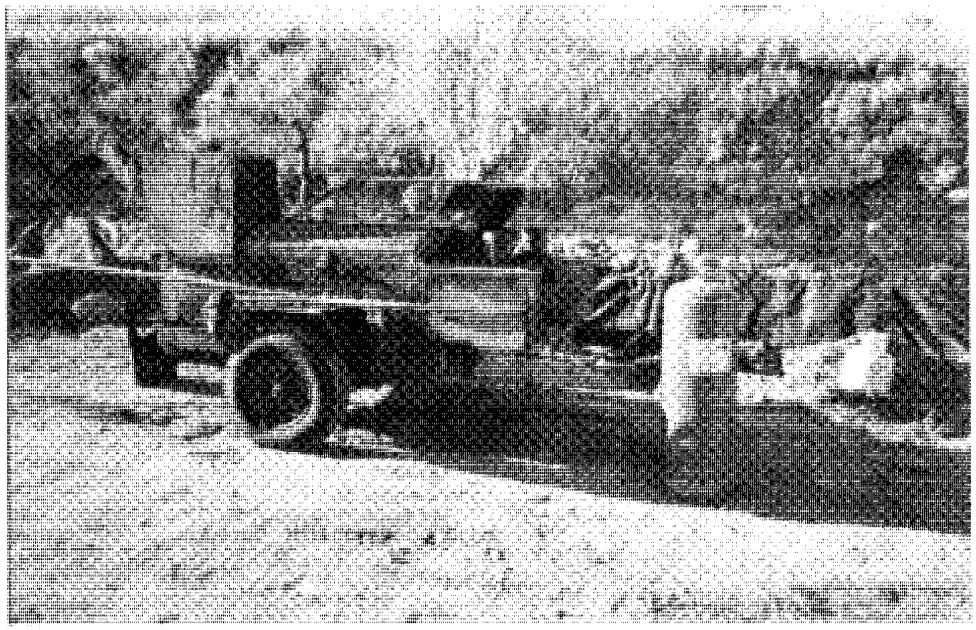


Photograph 16.—Three-man crew cleans the seam (removes loose dirt), applies hot glue, and holds seam shut until the glue cools and sets.

Bitter Root Irrigation District – Test Section BI-1
Exposed 20-mil EVA with 8-oz Geotextile Bonded to Both Sides

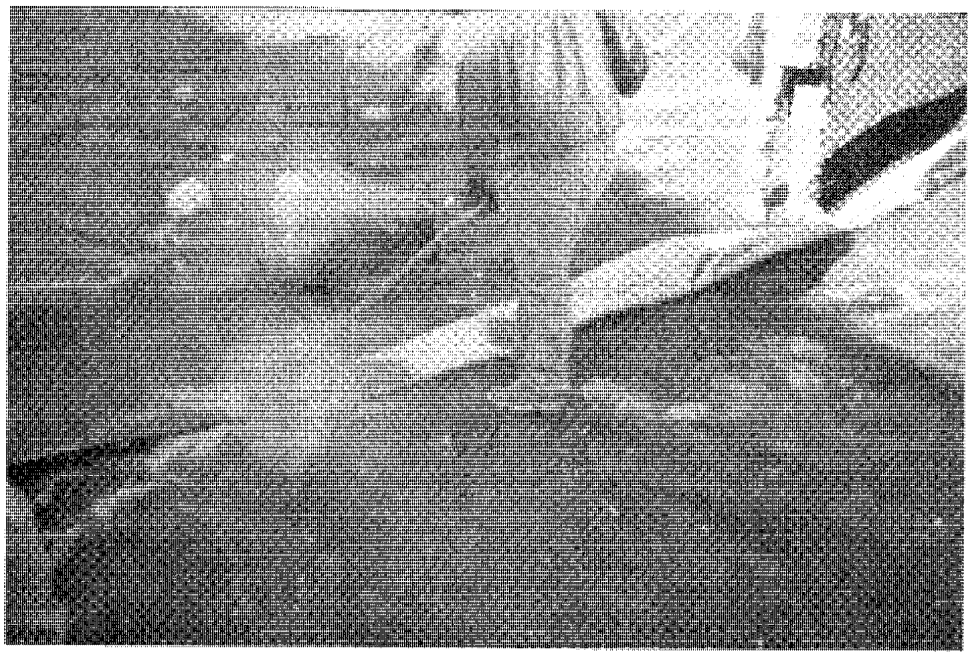


Photograph 17.—Lower portion of Photograph shows factory seam in the upper geotextile. Fishmouth in the seam has been folded over and glued shut.

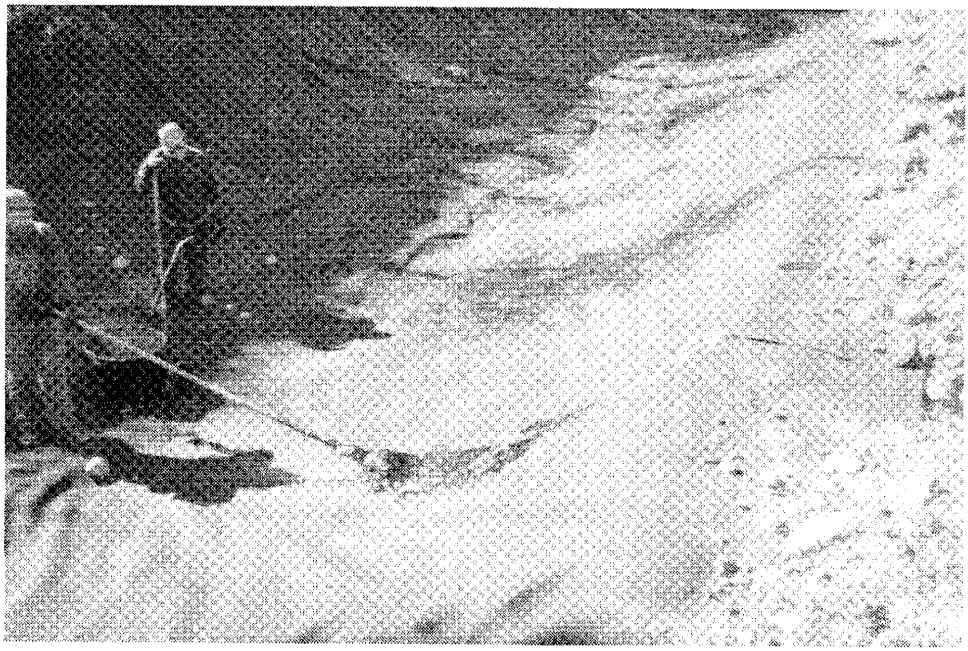


Photograph 18.—Hot tar was also used for seaming. Hot tar was supplied in a 100-gallon propane-fired kettle.

Bitter Root Irrigation District – Test Section BI-1
Exposed 20-mil EVA with 8-oz Geotextile Bonded to Both Sides



Photograph 19.—Geotextile is folded back, and hot tar is mopped onto both geotextile surfaces.

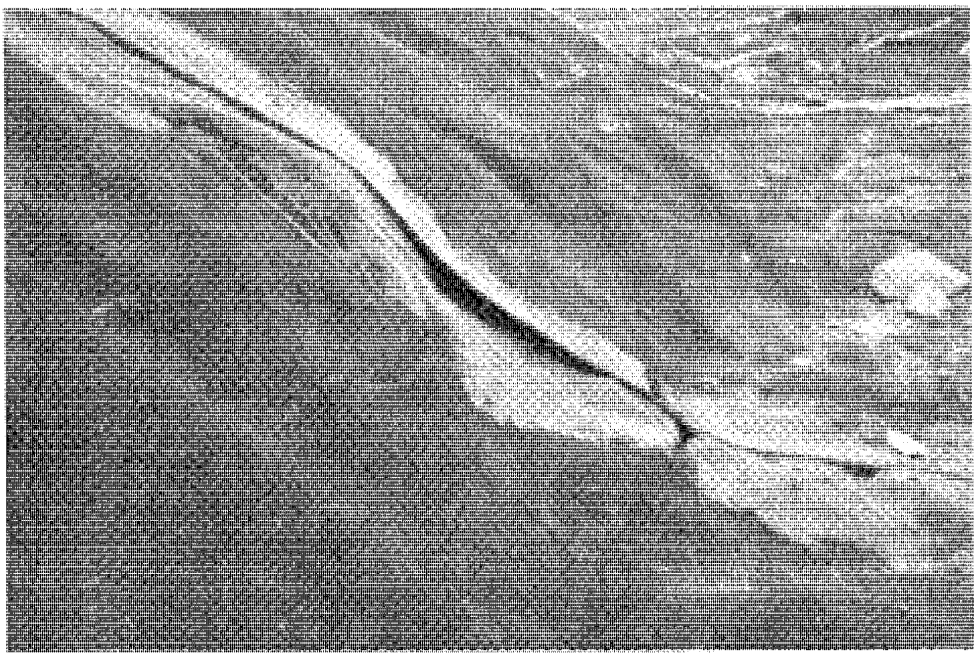


Photograph 20.—Upper geotextile is folded back into position, and the seam edge is buttered with hot tar.

Bitter Root Irrigation District – Test Section BI-1
Exposed 20-mil EVA with 8-oz Geotextile Bonded to Both Sides



Photograph 21.—Laborer on right uses hoe to hold seam closed while hot tar cools and sets.

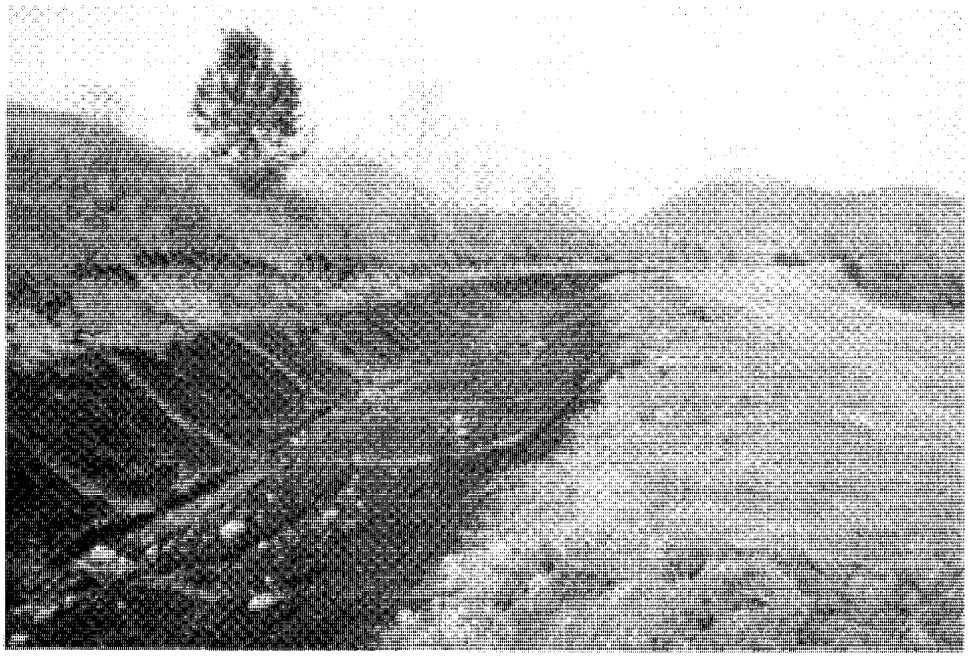


Photograph 22.—Seam with hot tar pops open if not held closed for sufficient time.

Bitter Root Irrigation District – Test Section BI-1
Exposed 20-mil EVA with 8-oz Geotextile Bonded to Both Sides



Photograph 23.—Finished installation.



Photograph 24.—Finished installation.

CHAPTER 3
CONDITION ASSESSMENT

Visual Inspections

All 34 test sections have been visually inspected annually to monitor the lining condition, assess durability, and evaluate maintenance requirements. Most inspections were performed in March 2002, when the Arnold test sections were 9½ to 10½ years old, the North Unit test sections were 3 to 10 years old, the Tumalo test sections were 5 to 8 years old, the Lugert-Altus test section was 8 years old, and the Juniper Flat test section was 4½ years old. The condition of each test section is summarized in tables 5, 6, and 7.

Table 5.—10-Year Condition Assessment - Arnold Test Sections

#	Test Section	Age	Condition	Comments
A-1	4-mil PE geocomposite with Shotcrete cover	10 years	Excellent	No problems.
A-2	30-mil VLDPE with Shotcrete cover	9½ years	Excellent	No problems.
A-3	Exposed 80-mil HDPE	9½ years	Excellent	Several small tears and cuts.
A-4	Exposed 30-mil PVC geomembrane with geotextile UV cover	10 years	Good	Several small tears and cuts.
A-5	Exposed 45-mil Hypalon with 16-oz geotextile cushion	10 years	Fair	Several small tears and cuts.
A-6	Exposed 36-mil Hypalon with 8-oz geotextile cushion	10 years	Fair	Several small tears and cuts.
A-7	40-mil PVC with 3-inch Grout-filled Mattress	10½ years	Excellent	Needs minor repairs.
A-8	3-inch Grout-filled Mattress	9½ years 10½ years	Excellent	Needs minor repairs.
A-9 A-10	Exposed VLDPE or HDPE with grout-filled mattress on side slopes only	28 months	Removed	Liner "whales" were impeding flow.

Table 6.—10-Year Condition Assessment - North Unit Test Sections

#	Test Section	Age	Condition	Comments
N-1	SPF with Futura 500/550 Protectibe Coating	5 years	Removed	Foam failed over first few years Replaced with RCC-Shotcrete.
N-2	SPF with Futura 500/550 Protectibe Coating	5 years	Removed	Foam failed over first few years Replaced with RCC-Shotcrete.
N-3	Tietex Geotextile with Geothane 5020 Protectibe Coating	6 months	Removed	Failed during first water run Replaced with RCC-Shotcrete.
N-4	Phillips Geotextile with Geothane 5020 Protectibe Coating	6 months	Removed	Failed during first water run Replaced with RCC-Shotcrete.
N-5	RCC invert Shotcrete side slopes	4 years 3 years	Very Good Excellent	Some water erosion of RCC invert.
N-6	Shotcrete with steel fibers	10 years	Excellent	Voids on left bank.
N-7	Shotcrete with polyfibers	10 years	Excellent	No problems.
N-8	Shotcrete with polyfibers	10 years	Excellent	No problems.
N-9	Unreinforced Shotcrete	10 years	Excellent	No problems.

Table 7.—Condition Assessment - Tumalo, Lugert-Altus, and Juniper Flat Test Sections

#	Test Section	Age	Condition	Comments
T-1	Liquid Boot over an Existing Concrete Flume	5 years	Poor	Poor bond to concrete Replaced with buried pipe.
T-2	Liquid Boot over a Sandblasted Steel Flume	8 years	Very Good	50+ blisters Replaced with buried pipe.
T-3	Liquid Boot over a Broomed Steel Flume	5 years	Very Good	50+ blisters Replaced with buried pipe.
L-1	Exposed 160-mil Teranap Bituminous Geomembrane	8 years	Excellent	Repaired partial washout in 1996. No further problems.
J-1	Exposed 160-mil Teranap Bituminous Geomembrane	4½ years	Excellent	No problems.
F-1	Exposed 45-mil Reinforced Polypropylene	3 years	Excellent	No problems.
O-1	Buried GCL	3 years	Very Good	No problems.
O-2	Exposed GCL	3 years	Very Good	Buried after 3 years.
O-3	Exposed 45-mil EPDM	2½ years	Excellent	No problems.
0-4	Exposed 30-mil LLDPE	2½ years	Excellent	Minor animal hoof damage.
O-5	Exposed 160-mil Colas Bituminous Geomembrane	1½ years	Excellent	No problems.
TF-1	Exposed 40-mil Wet-applied Polyurethane Geocomposite	2 years	Very Good	Needs minor repairs.
LO-1	Exposed 45-mil Reinforced Metallocene	2 years	Excellent	No problems.
BU-1	Exposed 60-mil White Textured HDPE	1 year	Excellent	No problems.
BI-1	Exposed 20-mil EVA Geocomposite	1 year	Excellent	No problems.

Ice Jams - Many canals, including the Arnold Canal, do not have enough slope to drain some areas 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.) which can restrict flow and 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 that do not have adequate natural slope.

Reduced Capacity - The Arnold Canal also 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.

Maintenance

To evaluate maintenance needs, the 34 test sections have been divided into three broad categories: concrete (with and without geomembrane underliner), exposed geomembrane, and spray-applied membranes. (See table 8.)

Table 8.—Categories of the test sections

Concrete		Exposed Geomembrane		Fluid-Applied Membrane	
A-1	PE Geocomposite with Shotcrete cover	A-3	Exposed 80-mil HDPE	N-1	Spray foam with coating
A-2	VLDPE with Shotcrete	A-4	PVC with geotextile cover	N-2	Spray foam with coating
A-7	PVC with grout mattress	A-5	Exposed 36-mil Hypalon	N-3	Geotextile with coating
A-8	3-inch grout mattress	A-6	Exposed 45-mil Hypalon	N-4	Geotextile with coating
A-9	VLDPE with grout mattress side slope	L-1	Bituminous geomembrane	T-1	Liquid Boot over concrete
A-10	HDPE with grout mattress side slope	J-1	Bituminous geomembrane	T-2	Liquid Boot over steel
N-5	RCC with Shotcrete side slope	F-1	Reinforced polypropylene	T-3	Liquid Boot over steel
N-6	Shotcrete with steel fibers	O-2	Exposed GCL	TF-1	Wet-applied polyurethane
N-7	Shotcrete with polyfibers	O-3	Exposed EPDM		
N-8	Shotcrete with polyfibers	O-4	Exposed LLDPE		
N-9	Unreinforced Shotcrete	O-5	Bituminous geomembrane		
O-1	Buried GCL	LO-1	Reinforced Metallocene		
		BU-1	White textured HDPE		
		BI-1	EVA geocomposite		

In general, the concrete liners are in the best condition because (1) concrete is quite durable and needs little maintenance and (2) the districts are familiar with concrete and are comfortable performing any needed repairs. Conversely, the exposed geomembranes and spray applied membranes need more repairs because of mechanical damage (animal traffic, maintenance equipment, vandalism, etc.) and UV attack. Also, field personnel are less familiar with geomembranes and therefore less likely to perform the required maintenance. Finally, special equipment and training is usually needed to repair the exposed geomembranes. Based on these findings, the following annual maintenance costs have been developed

Concrete	\$0.005 per ft^2
Exposed geomembrane	\$0.010 per ft^2
Spray-applied membrane	\$0.010 per ft^2

The concrete maintenance cost is based on a two-man crew repairing a 1-mile section of 40-foot-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 districts maintenance activities for each test section are summarized in tables 9, 10, 11, and 12. Note that many test sections need repairs that have not yet been performed. If repairs are not performed on a regular basis, minor repairs can turn into large, expensive repairs.

Table 9.—Maintenance Assessment for the Arnold Test Sections

Section No.	Test Section Material Type	Maintenance Requirements	Maintenance Preformed	Additional Maintenance Needed
A-1	4-mil PE geocomposite with Shotcrete cover	Minimal	Raised freeboard near highway bridge	Patch 1 or 2 small holes in the Shotcrete and raise the freeboard in 2 or 3 locations.
A-2	30-mil VLDPE with Shotcrete cover	Minimal	None	Raise the freeboard in 2 or 3 locations.
A-3	Exposed 80-mil HDPE	Minimal	Patched with concrete pad at sta. 20+00	Patch 4 to 6 small tears in the geomembrane.
A-4	Exposed 30-mil PVC geomembrane with geotextile UV cover	Minimal	Patched with concrete pad at sta. 20+00 Patched with concrete pad at sta. 20+20 Patched with concrete pad at sta. 30+00	Sew 1,000 feet of geotextile seams and repair several small tears in the geomembrane.
A-5	Exposed 45-mil Hypalon with 16-oz geotextile cushion	Extensive	Patched with concrete pad at sta. 30+00 Tried using a new tape for seams	Patch numerous tears in the geomembrane.
A-6	Exposed 36-mil Hypalon geocomposite with 8-oz geotextile cushion	Extensive	Tried using a new tape for seams	Patch several tears in the geomembrane.
A-7	40-mil PVC with 3-inch grout-filled mattress cover	Minimal	None	Patch several small holes in grout mattress.
A-8	3-inch grout-filled mattress	Minimal	None	Patch several small holes in grout mattress Patch 2- by 4-ft void in invert at 48+80.
A-9	Exposed 60-mil VLDPE with grout-filled mattress on side slopes only	Extensive	Concrete pad at Sta. 55+00, placed ballast over liner whales Removed geomembrane from invert	Test section abandoned at District's request.
A-10	Exposed 60-mil HDPE with grout-filled mattress on side slopes only	Extensive	Removed cement deposits, placed ballast over liner whales Removed geomembrane from invert	Test section abandoned at District's request.

Table 10.—Maintenance assessment for the North Unit Test Sections

Section No.	Test Section Material Type	Maintenance Requirements	Maintenance Preformed	Additional Maintenance Needed
N-1	SPF with Futura 500/550 protective coating	Extensive	Removed wash-out foam from down stream siphon and installed trash rack.	Replaced with RCC-Shotcrete.
N–2	SPF with Geothane 5020 protective coating	Extensive	Removed wash-out foam from down stream siphon and installed trash rack.	Replaced with RCC-Shotcrete.
N–3	Tietex geotextile with Geothane 5020 protective coating	Extensive	Patched holes in geotextile lining, removed wash-out geotextile, and repaired damaged pipe crossing.	Replaced with RCC-Shotcrete.
N–4	Phillips geotextile Geothane 5020 protective coating	Extensive	Patched holes in geotextile lining, removed wash-out geotextile, and repaired damaged pipe crossing.	Replaced with RCC-Shotcrete.
N–5	RCC invert with Shotcrete side slopes	Minimal	Patched eroded RCC at dozer tracks.	Patch additional eroded areas in RCC.
N–6	Shotcrete with Novocon steel fibers	Minimal	Patched several small holes in Shotcrete, removed large rocks, and caulked cracks.	Patch several small holes in Shotcrete.
N–7	Shotcrete with Phillips polyfibers	Minimal	Patched a couple of small holes in Shotcrete.	None
N–8	Shotcrete with fibermesh polyfibers	Minimal	Caulked some small cracks.	None
N–9	Unreinforced Shotcrete	Minimal	Patched a couple of small holes in Shotcrete.	None

Table 11.—Maintenance Assessment for the Tumalo Main Canal and the Ochoco Main Canal - Tumalo Irrigation District and Ochoco Irrigation District

Section No.	Test Section Material Type	Maintenance Requirements	Maintenance Preformed	Additional Maintenance Needed
T-1	Liquid Boot over an old concrete flume	Extensive	Completely disbonded in the invert.	Replaced with buried pipe.
T-2	Liquid Boot over an old sandblasted steel flume	Moderate	Patched dozens of blisters, mostly in the invert.	Replaced with buried pipe.
T-3	Liquid Boot over an old broomed steel flume	Moderate	Patched dozens of blisters, mostly in the invert.	Replaced with buried pipe.
O-1a	Covered Bentomat DN	None	None	None
O-1b	Covered Bentomat CL	None	None	None
O-2a	Exposed Bentomat DN	Minimal	None	Buried to prevent further deterioration.
O-2b	Exposed Bentomat CL	Minimal	None	Buried to prevent further deterioration.
O-3a	Exposed 45-mil EPDM with geotextile cushion on side slopes	None	None	None
O-3b	Exposed 45-mil EPDM with geotextile cushion on side slopes with covered invert	None	None	Check for hole in invert and patch.
O-4	Exposed 30-mil LLDPE with geotextile cushion on side slopes	Minimal	Patched holes from backhoe work around the ponding dike.	Monitor pinhole punchers and patch as needed.
O-5	Exposed 160-mil Coletanche NTP 2 ES	None	None	None

Table 12.—Maintenance assessment for the Lugert-Altus, Juniper Flat, Frenchtown, Rick Stone Ranch, Lewiston Orchards, Buffalo Rapids, and the Bitter Root Test Sections

Section No.	Test Section Material Type	Maintenance Requirements	Maintenance Preformed	Additional Maintenance Needed
LA-1	Exposed 160-mil Teranap geomembrane	Minimal	Repaired 300-foot washout in 1996 and patched a few minor holes.	Repair small hole on side slope.
J-1	Exposed 160-mil Teranap geomembrane	Minimal	Patched a couple of small holes and repaired a couple of seams.	None
F-1	Exposed 45-mil reinforced polypropylene over a steel flume	Minimal	None	Move shrubs away from flume.
TF-1	Exposed 40-mil wet applied polyurethane geocomposite	Minimal	None	Patch slits and rebury material in anchor trench.
LO-1	Exposed 45-mil reinforced metallocene	None	Raised freeboard at low spot.	None
BU-1a	Exposed 60-mil HDPE white textured with geotextile cushion	None	None	Repair anchor bench on banks.
BU-1b	Exposed 60-mil HDPE white	None	None	Repair anchor trench on banks.
BI-1	Exposed 20-mil EVA Geocomposite	Minimal	None	Repair a few seams.

DURABILITY

Arnold Irrigation District—Main Canal

Of the original 10 Arnold test sections, 8 are still in service and 2 were removed at the Arnold Irrigation District's (District) request because of problems with liner "whales" impeding flow. Figure 6 shows the location of the test sections. Visual inspections were performed during spring 2002.

Test Section A-1—

Material:	4-mil polyethylene (PE) geocomposite liner with Shotcrete cover
Description:	The polyethylene geocomposite is Phillips Petromat MB II, consisting of a 4-mil polyethylene geomembrane with a 4-ounce, non-woven geotextile bonded to each side. The specified Shotcrete thickness was 3 inches, minimum. Because of the irregular subgrade, the actual Shotcrete thickness averages 4 inches. This product is no longer available; however, a similar product is available from GeoComp Inc.
Construction cost:	\$2.43 per ft^2 \$2.50 per ft^2 with 1½-pound polyfiber
Date Installed:	February 1992 (10 years old)
Location:	Station 0+00 to 10+00 (1,000 linear feet; 30,000 square feet)
Condition:	Excellent - After 10 years of service, the Shotcrete lining is in excellent condition, completely protecting the underlying polyethylene geocomposite liner from weathering and mechanical damage. The most significant damage is moderate to extensive cracking of the Shotcrete 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. One small hole (3 x 6 inches) was found at the upstream end of the test section. No freeze-thaw damage was observed. Most of the invert had standing water, typically 6 to 12 inches deep. Lots of debris had collected in the canal, and two large sediment deposits (about 1 foot thick) had developed. The first half of the test section (about 400 linear feet) is unreinforced and has lots of transverse cracking (about every 20 feet), predominantly in the north (south-facing) side-wall. 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, UV, mechanical damage, vandalism, and animal damage. Where not covered by standing water, random cracks are often visible in the invert. Many of the cracks were previously marked with spray paint to aid in the

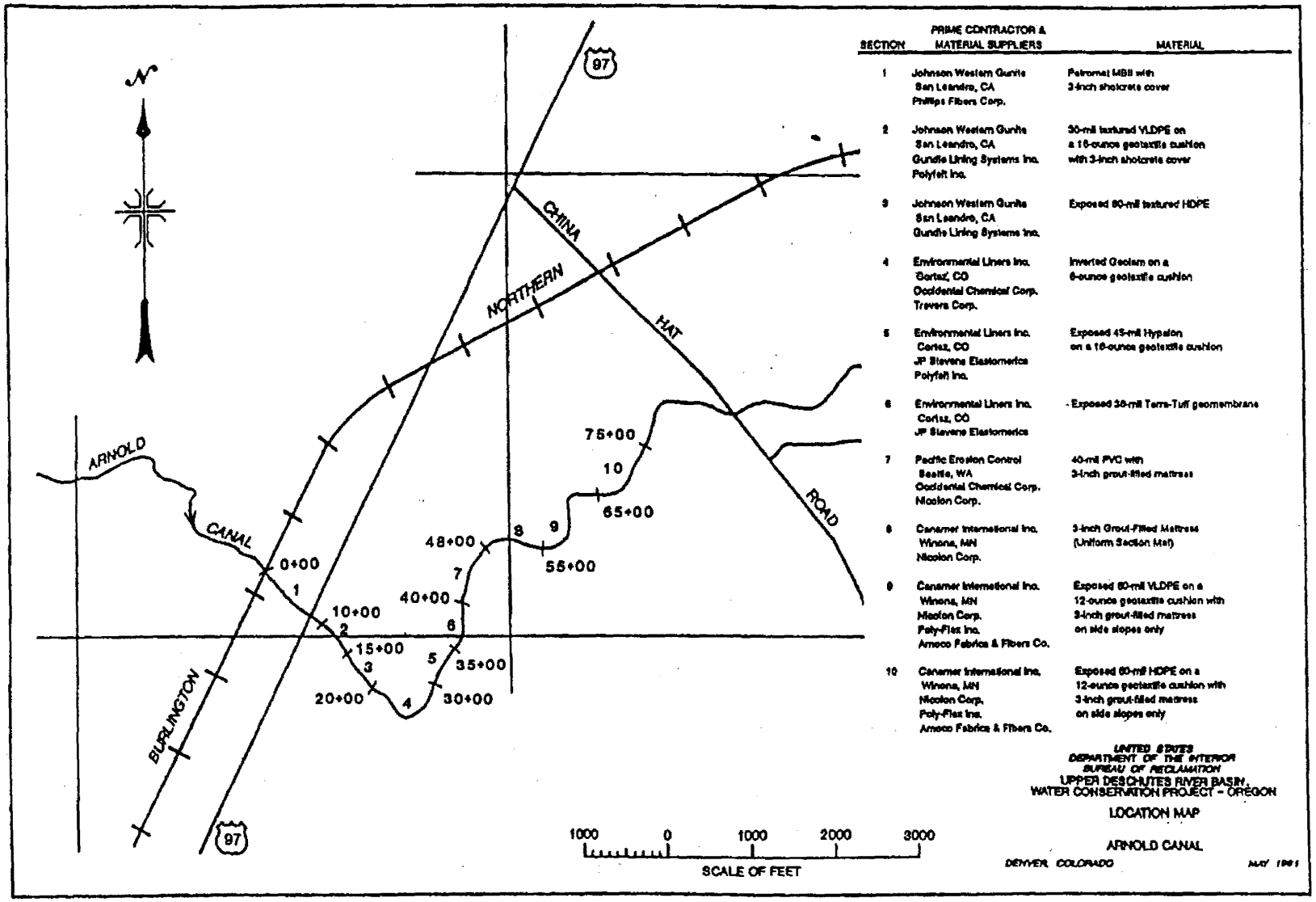


Figure 6.—Arnold Canal location map.

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 far fewer transverse cracks have developed in the side-walls (about every 50 feet).

In March 1994, about 100 linear feet of this test section was torn out and replaced when the bridge on Highway 97, 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 in excellent condition, 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 is not included in either the initial construction costs or in the maintenance costs.

A tree fell onto this test section during a wind storm in November 1994, but caused no damage to the Shotcrete lining.

Maintenance: Minimal maintenance required to date

Performed: Raised freeboard near highway bridge crossing.

Needed: Need to patch a couple of holes in the Shotcrete lining near the waterline to raise the freeboard (stations 0+50 and 9+00).

Photographs: 1 through 4

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

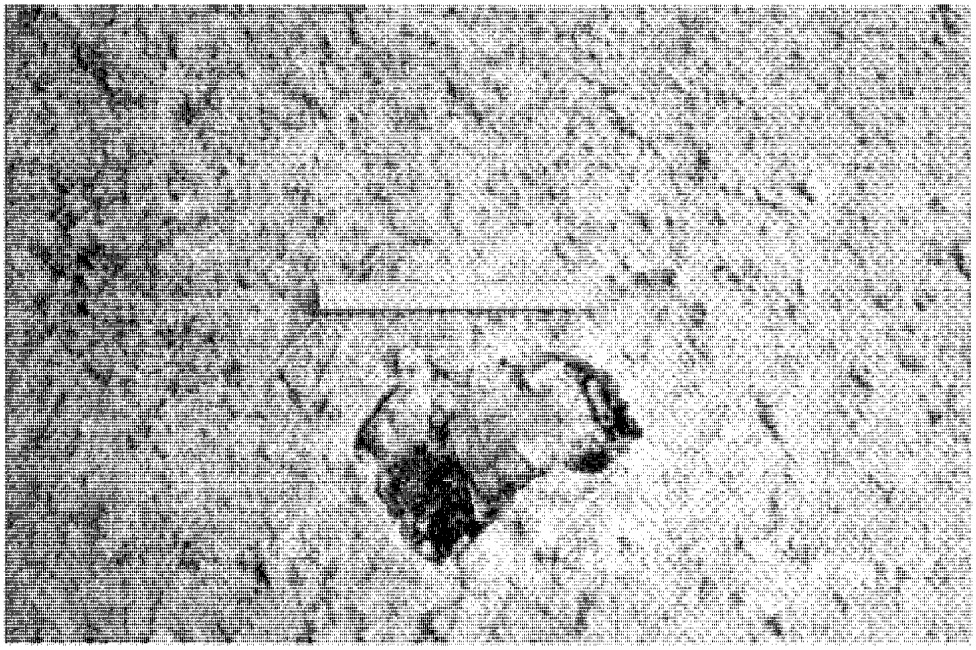


Photograph A-1.1.—Overview of the Arnold Canal Test Section A-1. Moderate to extensive cracking has been noticed in the upper tapered areas in the Shotcrete.

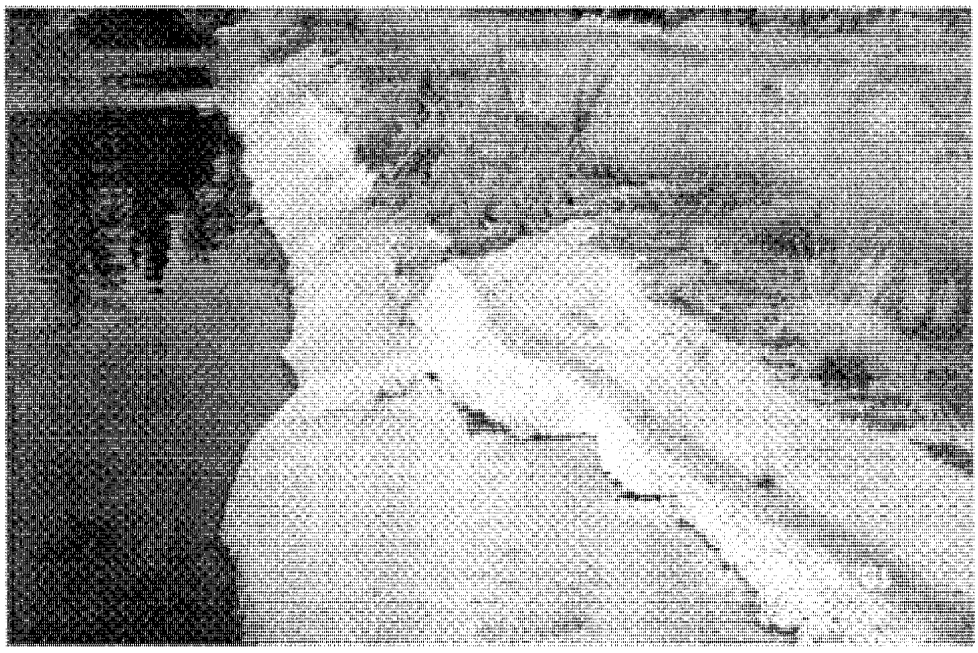


Photograph A-1.2.—View of canal with standing water. Note some sediment build up in the invert.

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



Photograph A-1.3.—View of 6 inch by 3 inch hole on side of canal.

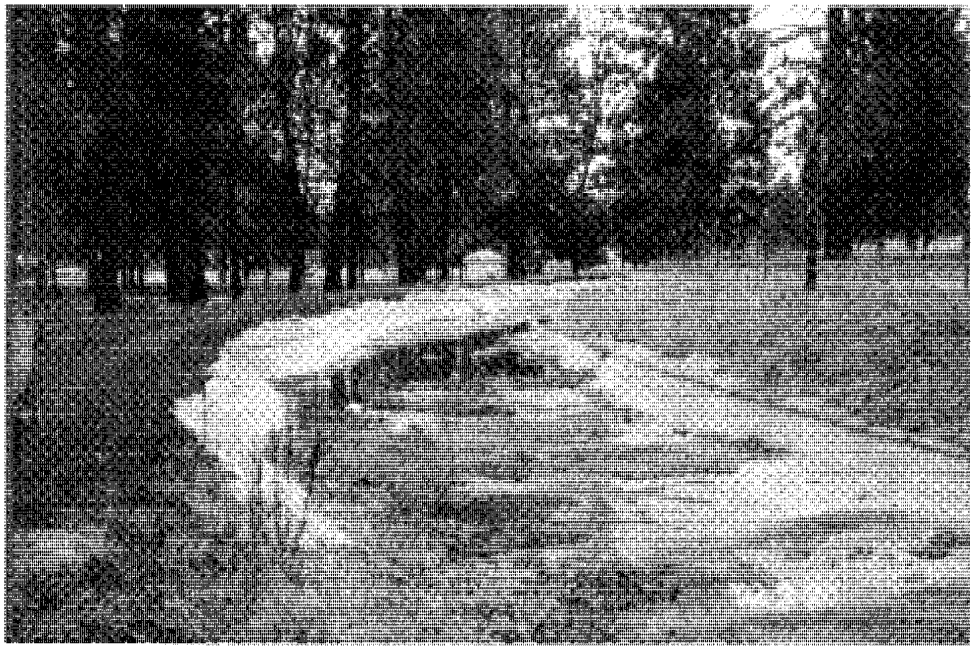


Photograph A-1.4.—View looking from the highway bridge to the west at Shotcrete that was added during the construction of the new highway overpass. The shotcrete needs to be extended upstream.

Test Section A-2—

Material:	30-mil textured VLDPE with 16-ounce geotextile cushion and Shotcrete cover
Description:	The VLDPE liner is 30-mil textured Hyperlastic manufactured by Gundle (now GSE Lining Technology Inc.). The geotextile cushion is Polyfelt TS-1000, a 16-ounce, needle-punched, non-woven geotextile. The specified Shotcrete thickness was 3 inches, minimum. Because of the irregular subgrade, the actual Shotcrete thickness averages 4 inches.
Construction Cost:	\$2.52 per ft^2
Date Installed:	October 1992 (9½ 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 9½ years, no freeze-thaw damage has been observed. Most of the invert is covered with standing water up to 12 inches deep. Little or no sediment has collected in the canal invert. Dozens of transverse contraction cracks have developed on both banks (every 10 to 20 ft). 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. Three small holes, approximately ½-inch diameter by 1 inch deep, were found in the Shotcrete on the south bank. It was not determined if these defects go clear through the Shotcrete. These defects may be the result of overspray during construction. They probably are not significant.
Maintenance:	Minimal maintenance required to date Performed: None Needed: Raise freeboard in a couple of spots
Photographs:	1 through 4

Arnold Canal - Test Section A-2
30-mil textured VLDPE with 16-ounce geotextile cushion and Shotcrete cover

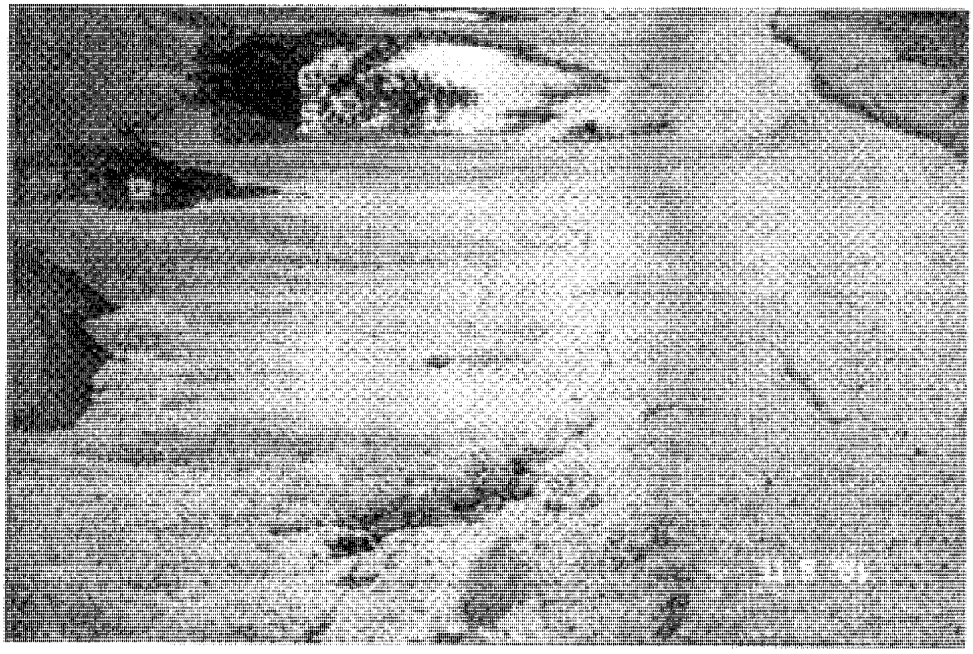


Photograph A-2.1.—Overview of the Arnold Canal Test Section A-2, which is in excellent condition.

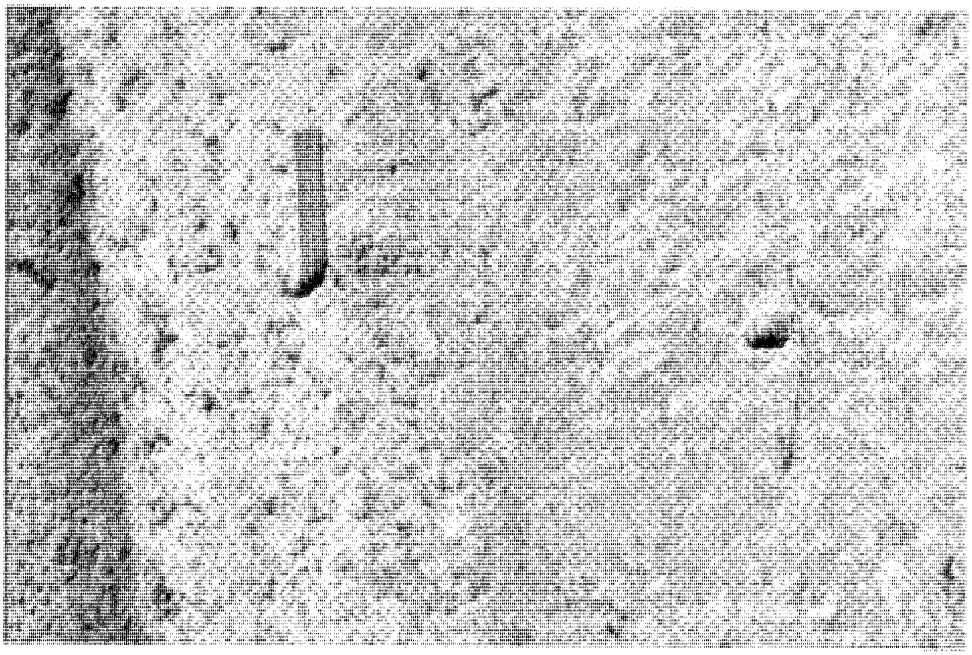


Photograph A-2.2.—Overview of the canal, moderate to severe cracking has been noticed in the upper tapered areas of the Shotcrete.

Arnold Canal - Test Section A-2
30-mil textured VLDPE with 16-ounce geotextile cushion and Shotcrete cover



Photograph A-2.3.—Some small shrinkage cracks that have developed over time.



Photograph A-2.4.—A few very small holes have shown up in the side slopes.

Test Section A-3—

Material:	Exposed 80-mil textured HDPE
Description:	HDPE liner is Gundle 80-mil textured Gundline HDT (Gundle is now GSE Lining Technology Inc.)
Construction Cost:	$1.38 per ft^2
Date Installed:	October 1992 (9½ years old)
Location:	Station 15+00 to 20+00 (500 linear feet; 15,000 square feet)
Condition:	Excellent - After 9½ years of service, the exposed HDPE liner was in excellent condition, with only minor mechanical damage. About half of this test section had standing water (typically 6 to 12 inches deep), with little to no sediment in the invert. Grass was growing in the sediment in a couple locations. The grass roots did not penetrate the geomembrane. A small tear at the upstream end (station 15+00) was probably caused by a backhoe removing the dike after the post-construction ponding tests. A small (3-inch long) tear over a subgrade rock was found in the invert (station 16+00). A semicircular tear (perhaps from an animal hoof) was present on the left bank, above the water line (station 18+50). The anchor trench on the left bank was holding up well. The rock cover (in lieu of an anchor trench) on the right bank is also performing satisfactorily. Little freeboard was 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 was torn where it was stretched tightly over a rock. The stainless steel battens at the bridge (station 17+50) were in excellent condition. The battens measure 2 inches wide by 3/16 inche 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. A sample (measuring 16 by 24 inches) was taken taken in November 2001 for laboratory testing. The liner was then patched with a hot-air welder.
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: Patches on half a dozen small tears in the liner. The repairs could be made with a small, hand-held extrusion welder or a hot-air welder.
Photographs:	1 through 6

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



Photograph A-3.1.—Overview of the Arnold Canal Test Section A-3, which is in excellent condition.

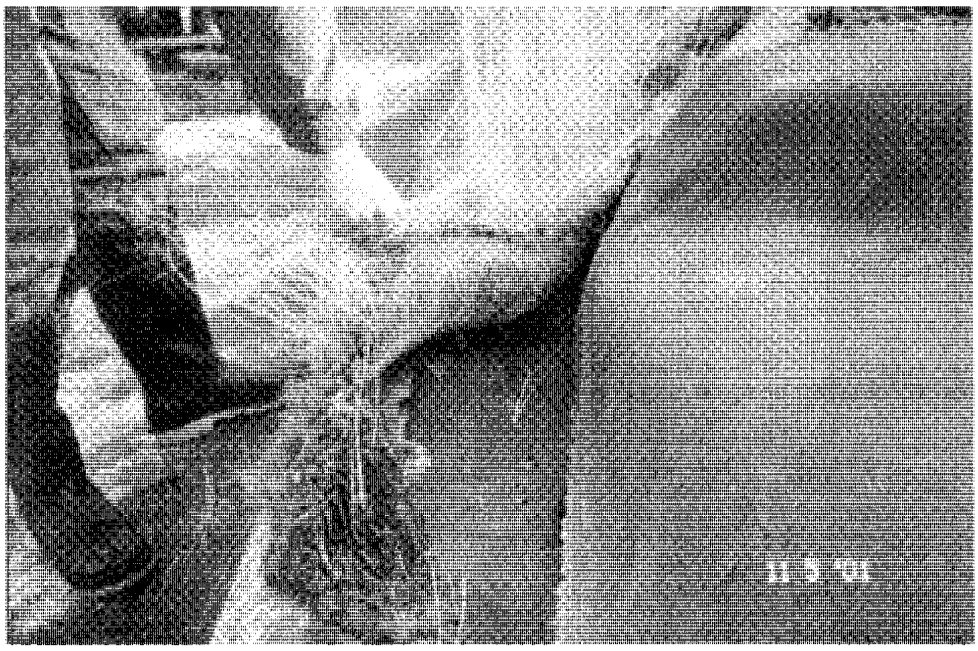


Photograph A-3.2.—Overview of the canal. Note standing water throughout the section.

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



Photograph A-3.3.—View of damage at the top of the liner.

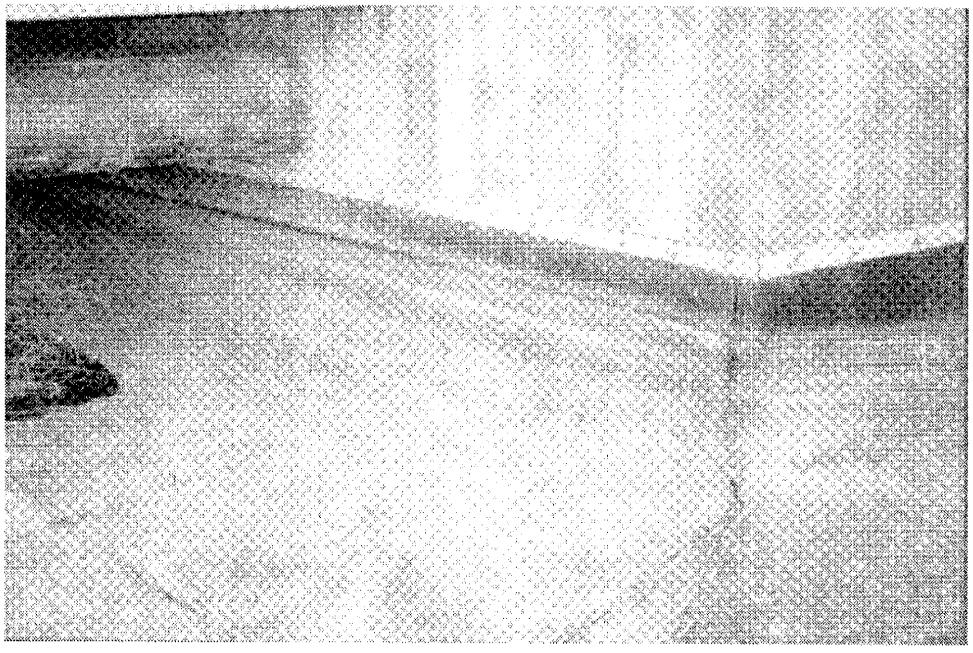


Photograph A-3.4.—View of grass growing in the wrinkles of the line. The roots do not penetrate the geomembrane.

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



Photograph A-3.5.—Patching of liner after 9½-year sample was removed for laboratory testing.



Photograph A-3.6.—Batten strips around the bridge in this section still look good and are preforming very well.

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-ounce, 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 ft^2
Date Installed:	March 1992 (10 years old)
Location:	Station 20+00 to 30+00 (1,000 linear feet, 30,000 square feet)
Condition:	Good - Performance is actually better than expected. The PVC held up well, but it was beginning to deteriorate. In some areas, the PVC had stiffened significantly and was showing some minor cracking,. In other areas, the PVC was still quite flexible. Surprisingly, these differences do not seem to relate to whether the PVC was above and below the waterline. The PVC may be experiencing a slight color change from gray to white where it is 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 it is unbonded at the 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. Lots 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. Vegetation is also growing in the protective geotextile just above the waterline. The roots appear to be growing in the geotextile and have not punctured the underlying PVC geomembrane. The subgrade is quite rough, and a number of pointed rock stress concentrations and tears 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 was repaired with a 1-foot by 1-foot concrete patch. A sample (measuring 16 by 24 inches) was taken in November 2001 for laboratory testing. A hot-air gun was used to patch the hole with 80-mil PVC-geotextile composite. Great care was needed to weld the new 80-mil PVC to the old 30-mil PVC without melting the 30–mil PVC.
Maintenance:	Minimal 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 foot- by 1-foot concrete cap over the tear, and it placed a 10-foot by 10-foot concrete pad in the invert at 20+20 to repair backhoe damage. In 2001, the District removed some of the large sediment deposits to improve flow. Great care was taken not to damage the exposed geomembrane during canal cleaning.

Needed: About 1,000 feet of geotextile seams need to be sewn to protect PVC geomembrane from UV degradation. Several small tears in the liner need to be repaired with a hot-air welder.

Photographs: 1 through 5

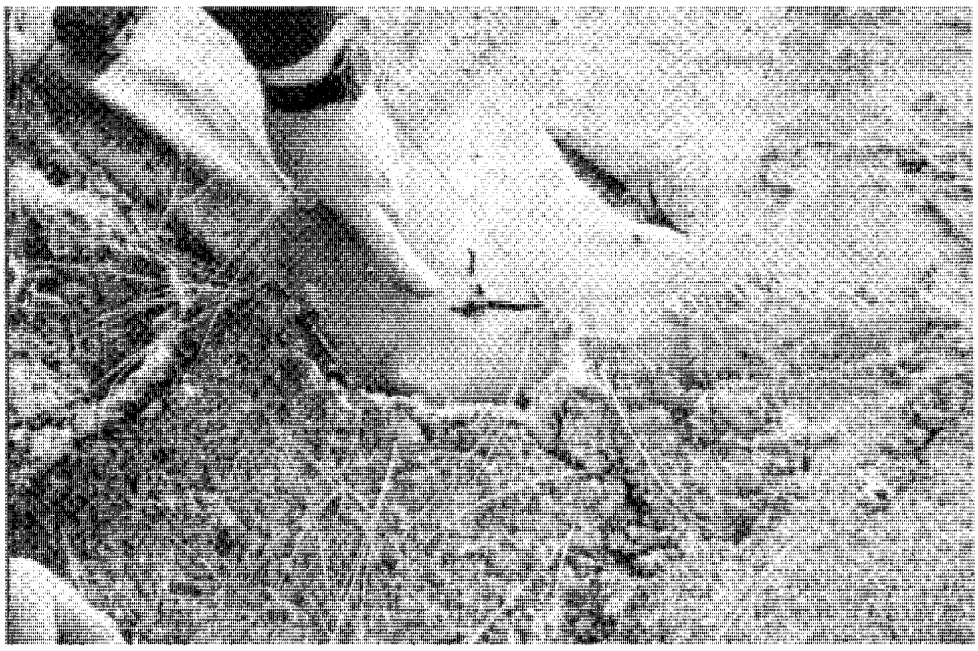


Photograph A-4.1.—View of the Arnold Canal Test Section A-4. This geocomposite is preforming very well under these conditions.

Arnold Canal - Test Section A-4
Exposed 30-mil PVC with geotextile UV cover

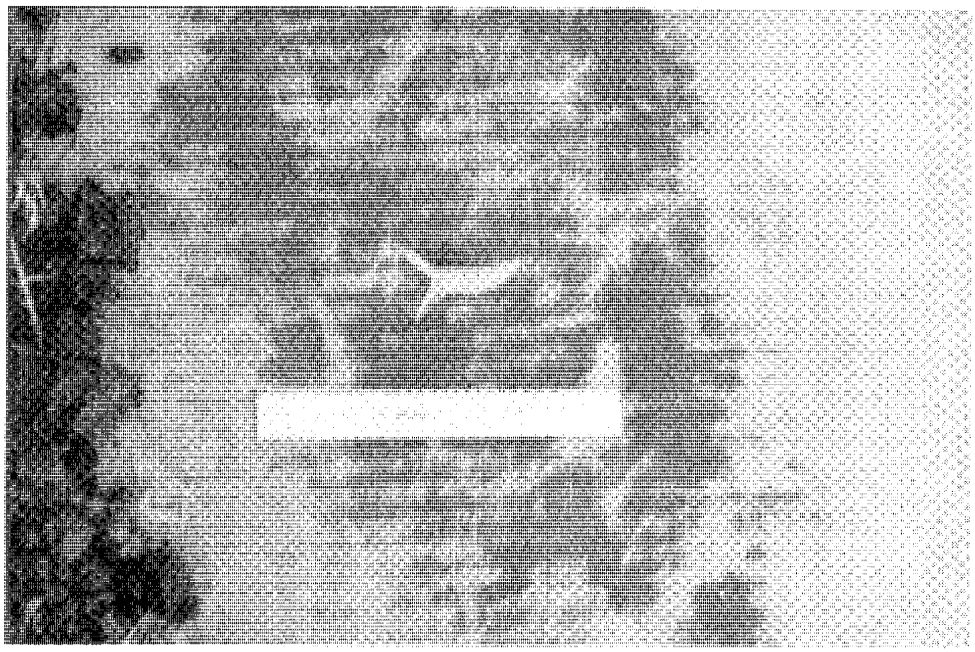


Photograph A-4.2.—View of some large sediment deposit in the canal. These may have to be removed to prevent a blockage.



Photograph A-4.3.—Liner damage (both natural and what appears to be a knife cut) can be seen in this photograph.

Arnold Canal - Test Section A-4
Exposed 30-mil PVC with geotextile UV cover



Photograph A-4.4.—Natural wear between the anchor trench and the water line. The material is somewhat brittle at these areas.



Photograph A-4.5.—Patching of the liner after a coupon was taken for testing by Reclamation.

Test Section A-5—

Material:	Exposed 45-mil Hypalon with 16-ounce geotextile cushion
Description:	The Hypalon membrane is JP Stevens 45-mil reinforced CSPE (chlorosulfonated polyethylene). The geotextile cushion is Polyfelt TS-1000, a 16-ounce, needle-punched, non-woven geotextile.
Construction Cost:	$1.11 per ft^2
Date Installed:	March 1992 (10 years old)
Location:	Station 30+00 to 35+00 (500 linear feet; 15,000 square feet)
Condition:	Fair - After 10 years, the exposed Hypalon geomembrane has numerous tears and is in need of repairs. If repaired, the condition could be upgraded to good or even very good. The longitudinal seams are still holding up well. The tears include about six minor tears up to 6 inches long and about six major "L"-shaped tears up to 3 feet long. All the tears are below the waterline. The District tried to repair the major tears with a commercial patching tape made specifically for geomembranes, but the tape did not adhere to the aged Hypalon. How the surface was prepared before the tape was applied is not known, but the extent of the preparation was probably minimal. Standing water covers almost the entire invert, typically 6 to 12 inches deep. Most of the test section has 1 to 4 inches of sediment, and a small amount of vegetation is 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 #4 rebar has been driven through the hypalon liner on the top of the left bank at station 31+00, but it 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). A sample (measuring 16 by 24 inches) was taken taken in November 2001 for laboratory testing. The liner was patched with a bodied Hypalon solvent. Before patching, the old Hypalon was prepared by wire brushing with Xylene to remove the surface layer of oxidized Hypalon. Because of the cool ambient tepmperatures (40 °F), heat from the hot-air gun was applied to the seam during rolling. Field repairs of Hypalon are difficult and time consuming.

Maintenance: Extensive maintenance required to date

Performed: In 1994, the District placed a concrete anchor pad at the upstream end (station 30+00). In about 2000, the District attempted to patch several "L"-shaped tears with commercial patching tape. In 2001, the District removed some of the large sediment deposits to improve flow. Great care was taken not to damage the exposed geomembrane during canal cleaning.

Needed: Numerous tears in the geomembrane need to be patched. Because of the surface preparation needed to patch the Hypalon, these repairs can be quite time consuming.

Photographs: 1 through 13

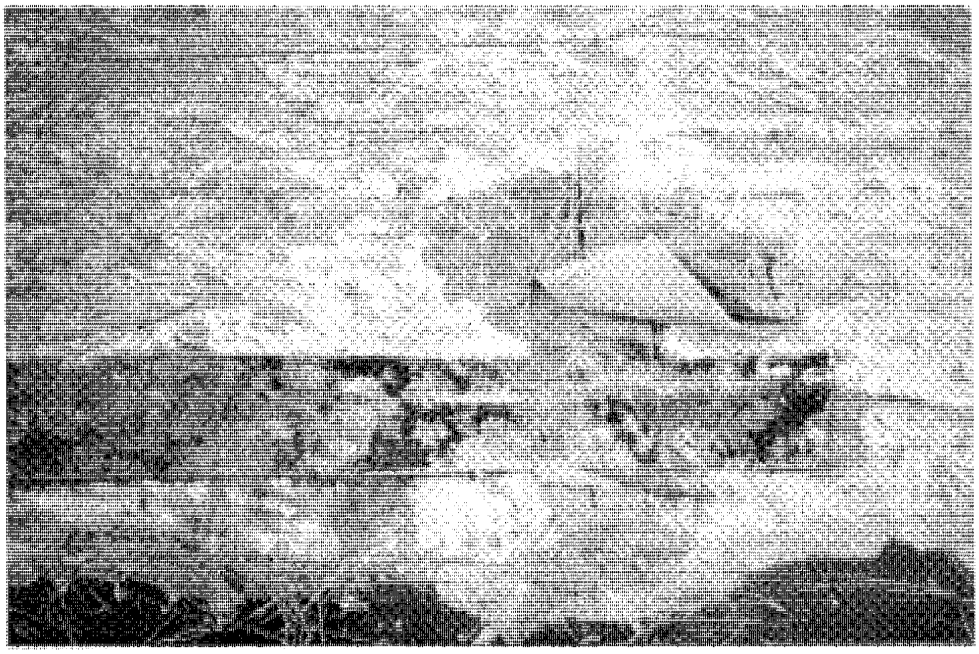


Photograph A-5.1.—Overall view of the Arnold Canal Test Section A-5. In the past 3 years this liner has deteriorated from "very good" to "fair" condition.

Arnold Canal - Test Section A-5
Exposed 45-mil Hypalon with 16-ounce geotextile cushion

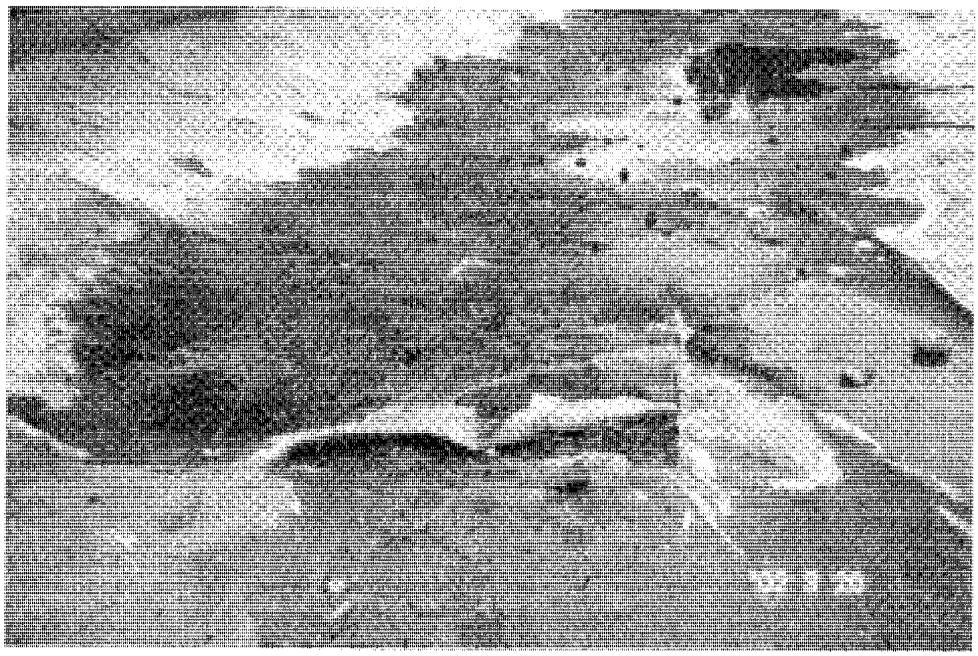


Photograph A-5.2.—View of the canal with some sediment in the invert. This sediment has helped to prolong the life of the geomembrane liner.

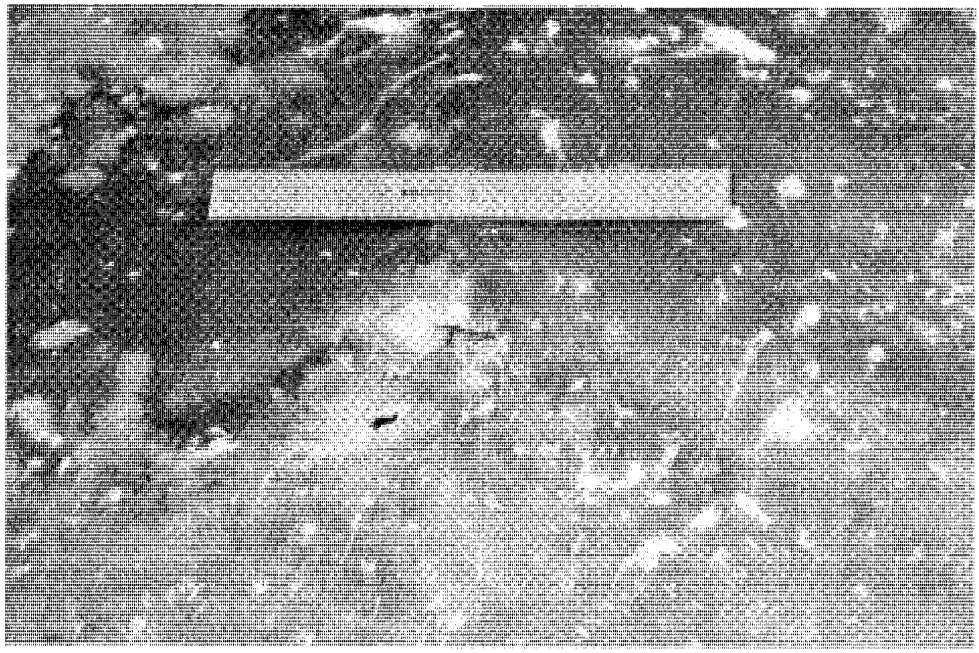


Photograph A-5.3.—Repair of torn areas with a tape material. It was not certain how long this tape would last or how well it bonded at the time of installation.

Arnold Canal - Test Section A-5
Exposed 45-mil Hypalon with 16-ounce geotextile cushion



Photograph A-5.4.—View of new torn area. Note the shape of the tear. Most tears seem to have an L-shape.



Photograph A-5.5.—One small worn area and one tear about 2 inches long.

Arnold Canal - Test Section A-5
Exposed 45-mil Hypalon with 16-ounce geotextile cushion



Photograph A-5.6.—View of subgrade stick protruding through liner. This stick punctured the liner shortly after initial construction. The tear has not gotten any worse since that time.



Photograph A-5.7.—View of the area selected for a trial patch. The area is being dried with a hot-air welding tool.

Arnold Canal - Test Section A-5
Exposed 45-mil Hypalon with 16-ounce geotextile cushion

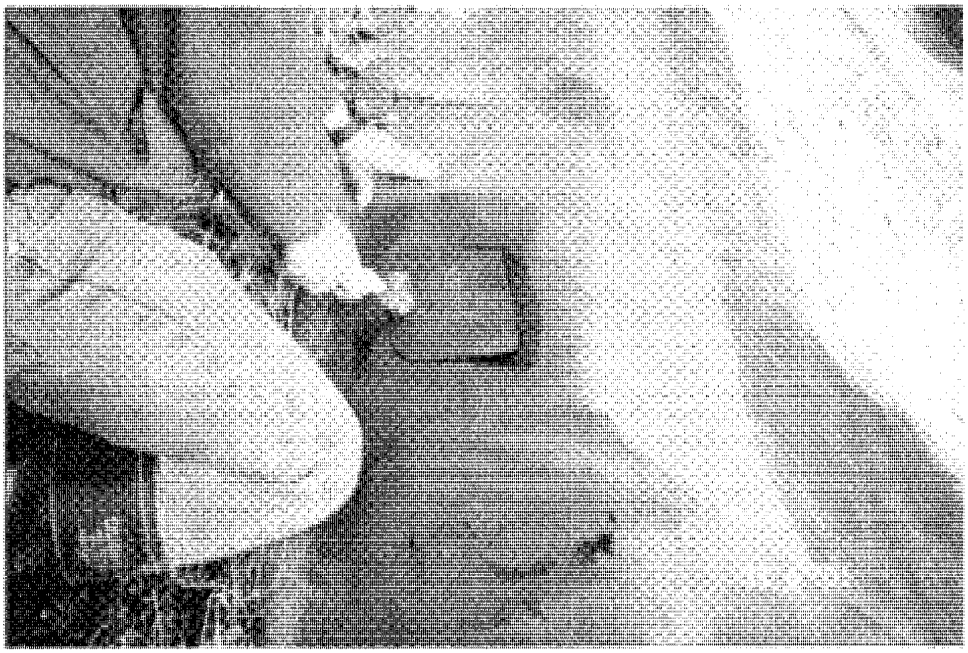


Photograph A-5.8.—Cleaning solvent being applied and wire brushed on the liner.

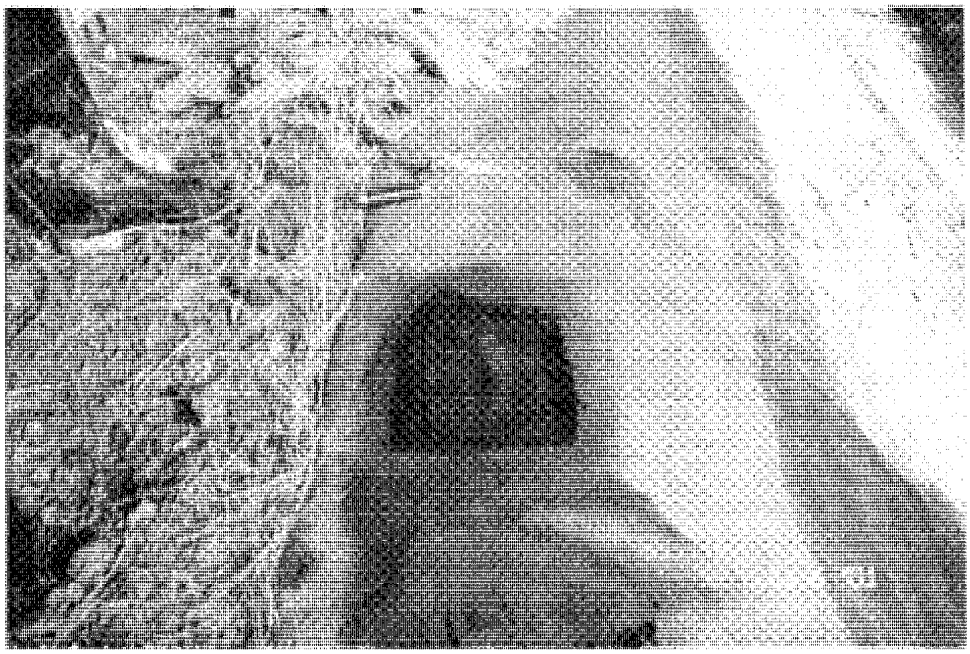


Photograph A-5.9.—Glue being brushed on the patch area after the solvent has dried.

Arnold Canal - Test Section A-5
Exposed 45-mil Hypalon with 16-ounce geotextile cushion



Photograph A-5.10.—Patch being rolled on the liner.

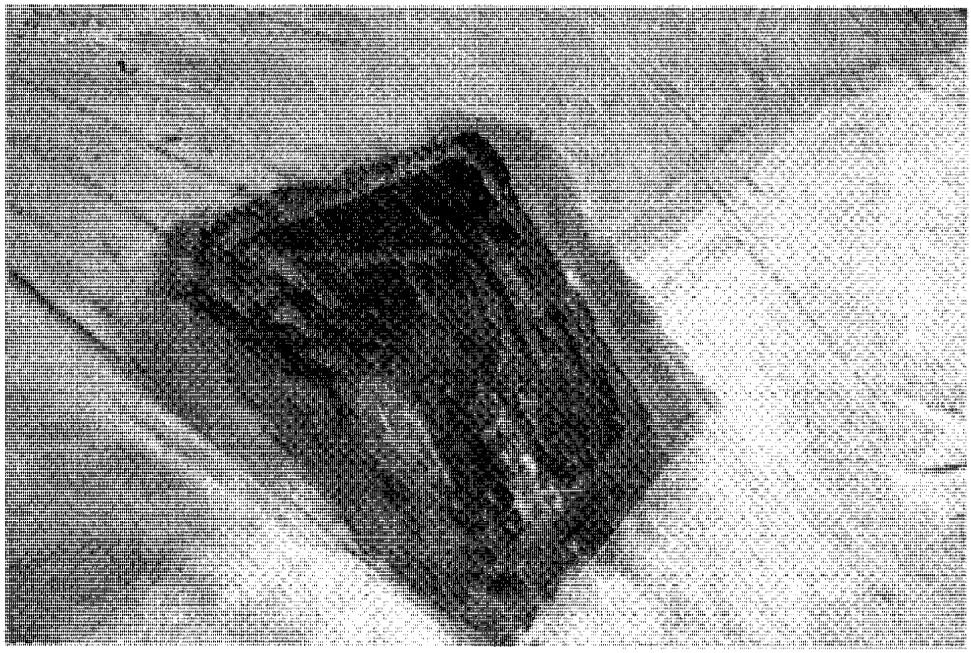


Photograph A-5.11.—View of completed patch.

Arnold Canal - Test Section A-5
Exposed 45-mil Hypalon with 16-ounce geotextile cushion



Photograph A-5.12.—View of actual sample area on the side slope. The sample has been removed and will be analyzed at Reclamation's lab.



Photograph A-5.13.—View of completed patch. Note that all samples removed were covering an area above and below the water line.

Test Section A-6—

Material:	Exposed 36-mil Hypalon with 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-ounce nonwoven PET (polyethylene terephthalate) geotextile cushion.
Construction Cost:	$1.03 per ft^2
Date Installed:	March 1992 (10 years old)
Location:	Station 35+00 to 40+00 (500 linear feet; 15,000 square feet)
Condition:	Fair - After 10 years, the exposed Hypalon geomembrane has numerous tears and is in need of repairs. If repaired, the condition could be upgraded to good or even very good. Included are about five minor tears up to 1 foot long and about four major "L"-shaped tears up to 3 feet long. Most of the tears are below the waterline. The district tried to repair the major tears with commercial patching tape; however, the tape did not adhere to the aged Hypalon. How the surface was prepared before the tape was applied is not known, but the preparation was probably minimal. The factory longitudinal seams are holding up well. Standing water covers most of the invert. It is typically 6 to 12 inches deep. Most 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 that is in good condition. A concrete cap at this location would facilitate future ponding tests. The original boot at the golf course turn-out looks good. A small tear in the Hypalon at the anchor trench (station 35+00 left) needs to be repaired. 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. In November 2001, a 16- by 24-inch sample was taken for laboratory testing. The liner was patched with a bodied Hypalon solvent. Before patching, the old Hypalon was wire brushed with Xylene to remove the surface layer of oxidized Hypalon. Because of the cool ambient temperatures (40 °F), heat from the hot-air gun was applied to the seam during rolling. Field repairs of Hypalon are difficult ad time consuming.

Maintenance: Extensive maintenance required to date

Performed: In 2000, the District attempted to patch large tears with commercial patching tape. In 2001, the District removed some of the large sediment deposits to improve flow. Great care was taken not to damage the exposed geomembrane during canal cleaning.

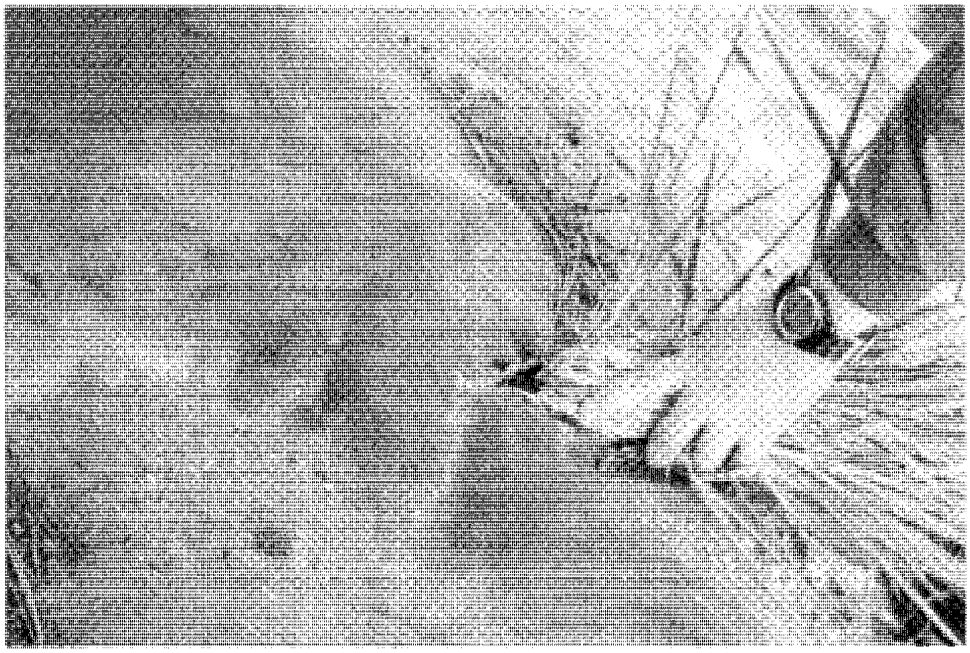
Needed: Several tears in the geomembrane, mostly below the waterline, need to be patched.

Photographs: 1 through 5

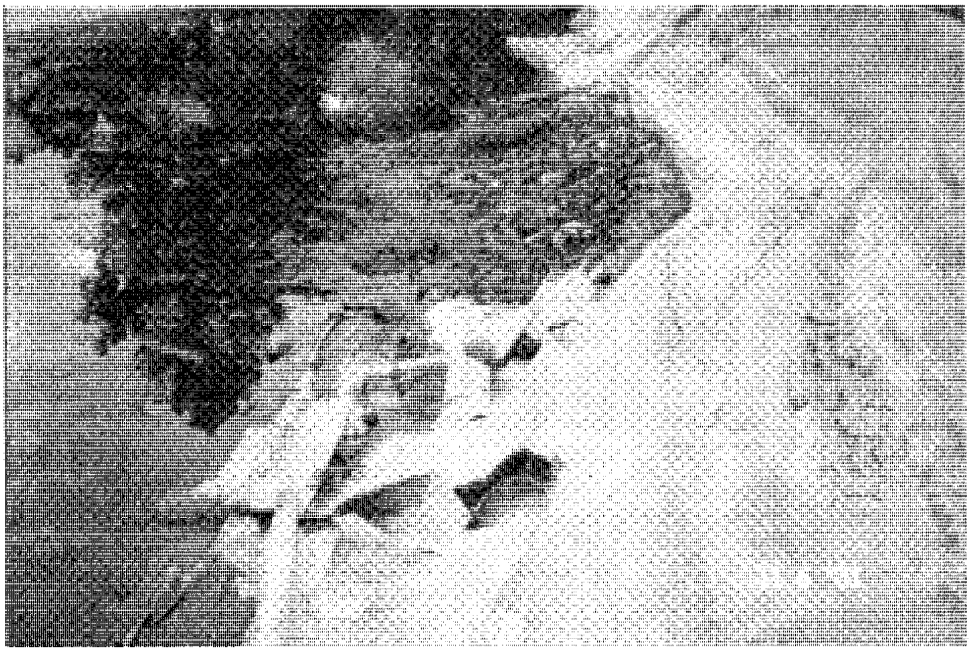


Photograph A-6.1.—Overview of the Arnold Canal Test Section A-6, which is in fair condition.

Arnold Canal - Test Section A-6
Exposed 36-mil Hypalon with 8-oz geotextile cushion

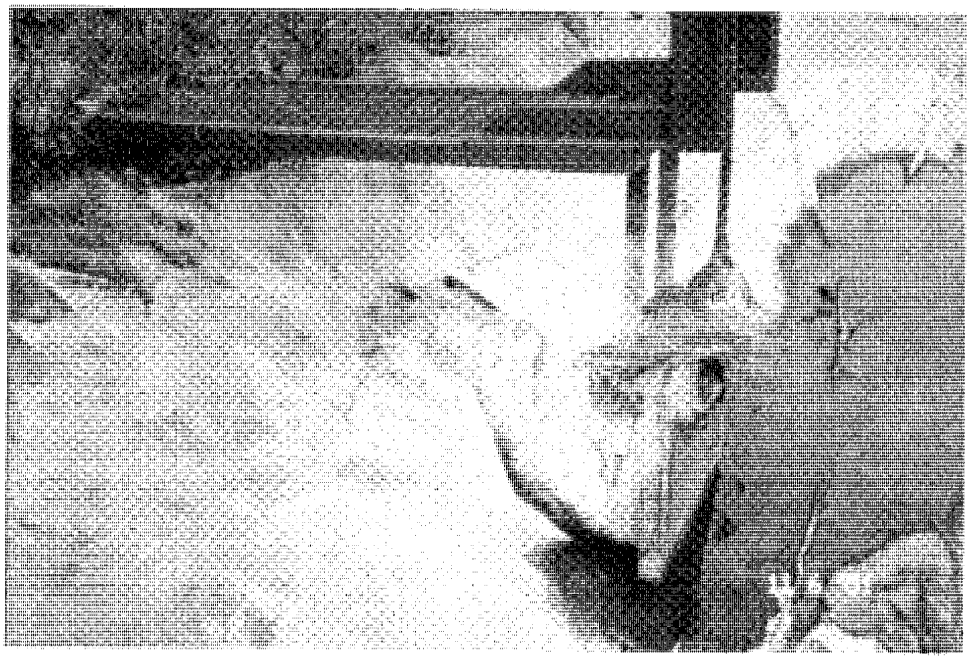


Photograph A-6.2.—View of grass coming through the liner at one of many tears.

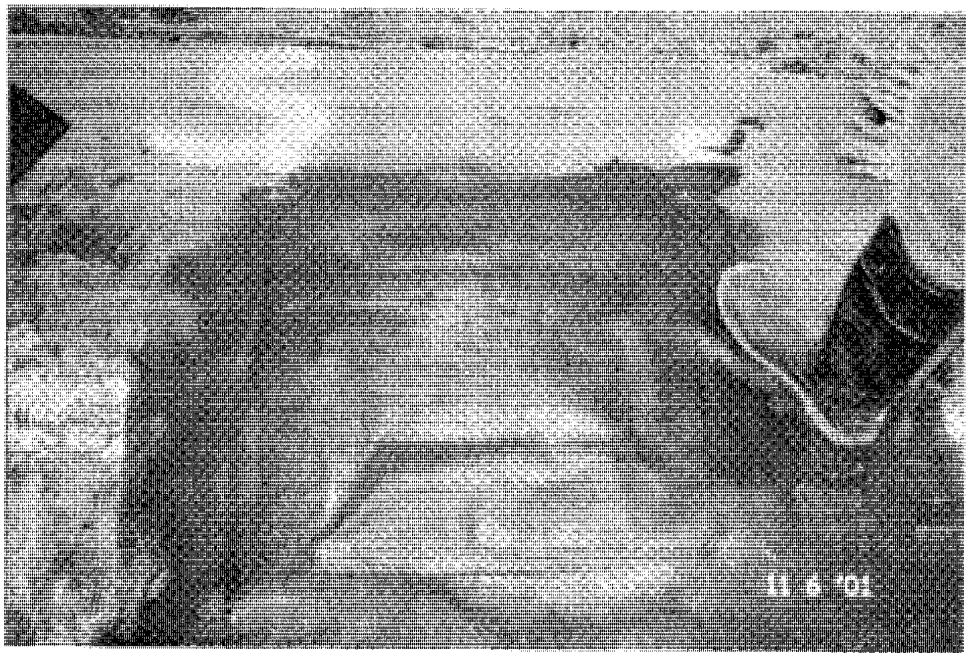


Photograph A-6.3.—This material has been torn in many areas. The tears are fewer than in A-5, perhaps because of the bonded textile.

Arnold Canal - Test Section A-6
Exposed 36-mil Hypalon with 8-oz geotextile cushion



Photograph A-6.4.—The boot and area around the pipe outlet is still in good shape.



Photograph A-6.5.—View of the completed patch after the sample was removed.

Test Section A-7—

Material:	40-mil PVC with 3-inch grout-filled mattress
Description:	40-mil Occidental Oxyflex PVC membrane that is covered with Nicolon Armorform 3-inch USM (Uniform Section Mat) grout-filled mattress
Construction Cost:	\$2.54 per ft^2
Date Installed:	November 1991 (10½ years old)
Location:	Station 40+00 to 48+00 (800 linear feet; 24,000 square feet)
Condition:	Excellent - After 10½ years, the grout-filled mattress is in excellent condition. It has only small, occasional defects. The grout-filled mattress is 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 has lots 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 continues to deteriorate, but is mostly intact. At about a half-dozen locations (including station 46+00), the grout was only about a ½ inch thick where it was installed over a subgrade rock, and the grout and geotextile have worn away, exposing the underlying PVC membrane. At station 44+50, the water surface is above the grout mattress on the left bank. Soil has washed-out about 2 feet deep behind the grout mattress. The PVC underliner could not be found behind the grout mattress in this area; however, the PVC was apparent in other areas. At station 40+50, the grout mattress was raised (patched) with Shotcrete where the grout mattress was below the waterline. A 2-inch void has developed between the concrete patch and the original grout mattress.
Maintenance:	Minimal maintenance required to date Performed: Shortly after original construction, the freeboard was raised with Shotcrete in one location. Needed: A half-dozen small holes in the grout mattress need to be repaired with sack-mix concrete. The freeboard needs to be raised where the grout mattress is below the waterline. A void between the shotcrete and the grout mattress needs to be repaired at station 40+50. If sediment is removed to improve flow, damage to the underlying geomembrane is not a concern because the geomembrane is protected by the grout mattress.
Photographs:	1 through 4

Arnold Canal - Test Section A-7
40-mil PVC with 3-inch grout-filled mattress

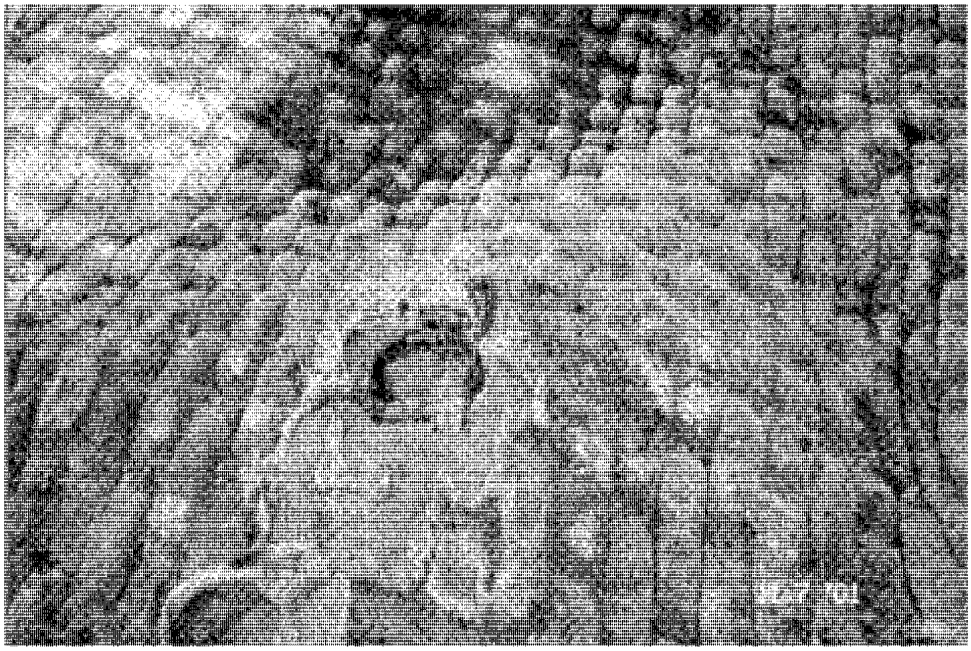


Photograph A-7.1.—Overview of the Arnold Canal Test Section A-7, which is in excellent condition.

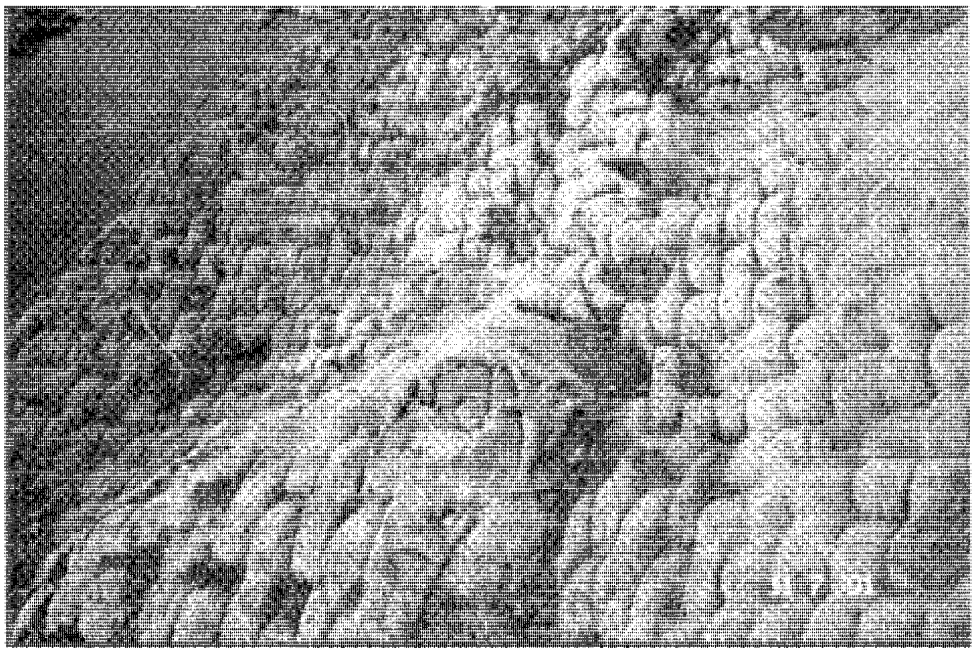


Photograph A-7.2.—Overview of the canal about midway in the test section.

Arnold Canal - Test Section A-7
40-mil PVC with 3-inch grout-filled mattress



Photograph A-7.3.—Weathering of the mattress material and a hole exposing the 40-mil PVC underliner.

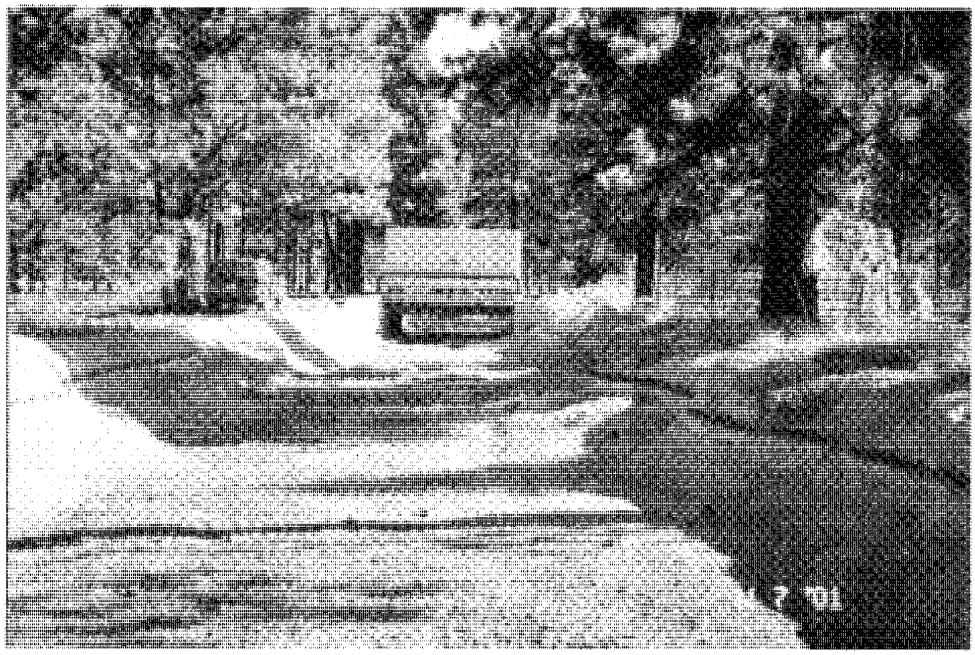


Photograph A-7.4.—View of a hole in the grout mattress exposing the under liner.

Test Section A-8—

Material:	3-inch grout-filled mattress
Description:	The grout-filled mattress is Nicolon Armorform 3-inch USM
Construction Cost:	\$1.92 per ft^2
Date Installed:	November 1991 (first 200 feet) 10½ years old November 1992 (500 additional feet) 9½ years old
Location:	Station 48+00 to 55+00 (700 linear feet; 21,000 square feet)
Condition:	Excellent - After 10 years, the grout-filled mattress is in excellent condition, with no freeze-thaw damage. The first 200 feet, which has zippered seams, has a much neater appearance than the second 500 feet, which has sewn seams. Both areas are fairly uniformly grouted in spite of the uneven rocky subgrade. At station 48+80, a large ungrouted area (2- by 4-ft) was found in the invert that was apparently never grouted. Surprisingly, the geotextile is still present after 10 years. Grass is growing at the waterline on top of the geotextile. The grass roots do not penetrate the grout mattress. A small amount of cement paste is present in the invert between the concrete "bricks." Except for one area with a large sand deposit (station 52+00 to 53+00), little 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 was securely tied to the bridge, and there were no gaps that would allow seepage. At station 54+50, the grout mattress has about a dozen holes (missing bricks) where the grout mattress is very thin. Most of the holes are above the waterline.
Maintenance:	Minimal maintenance required to date Performed: None Needed: A large void in the invert at station 48+80 and several small holes in the grout mattress near station 54+50 need to be patched.
Photographs:	1 through 6

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

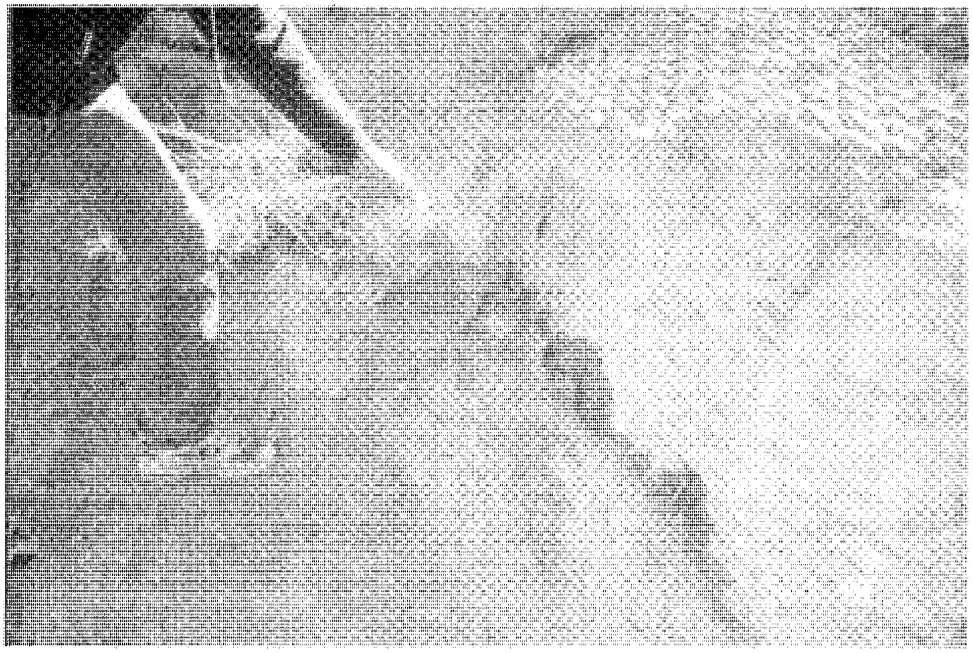


Photograph A-8.1.—Overview of the Arnold Canal Test Section A-8, which is in excellent condition.

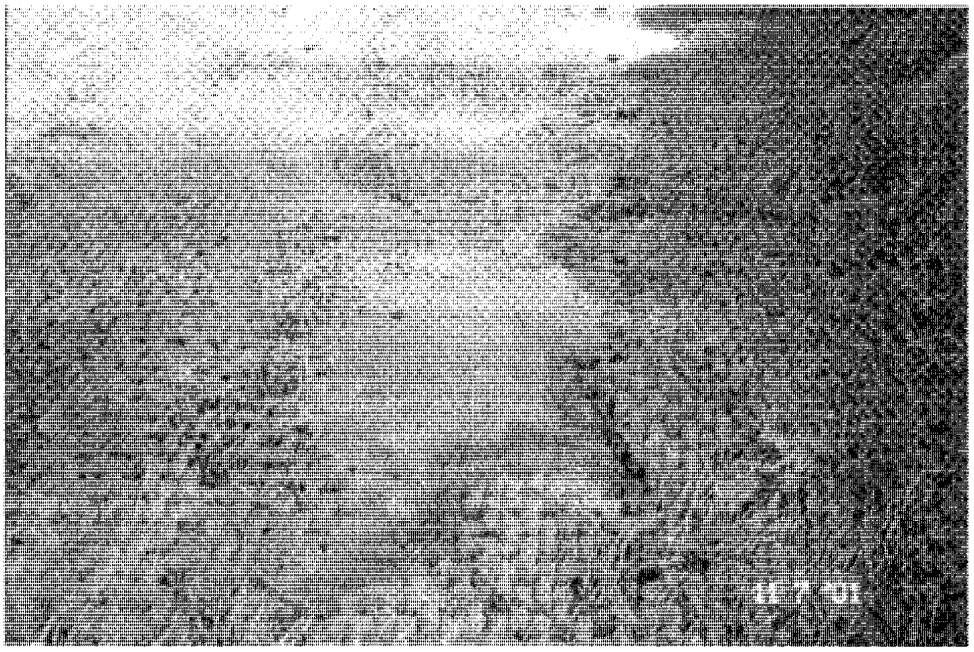


Photograph A-8.2.—View of the canal from the bridge.

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

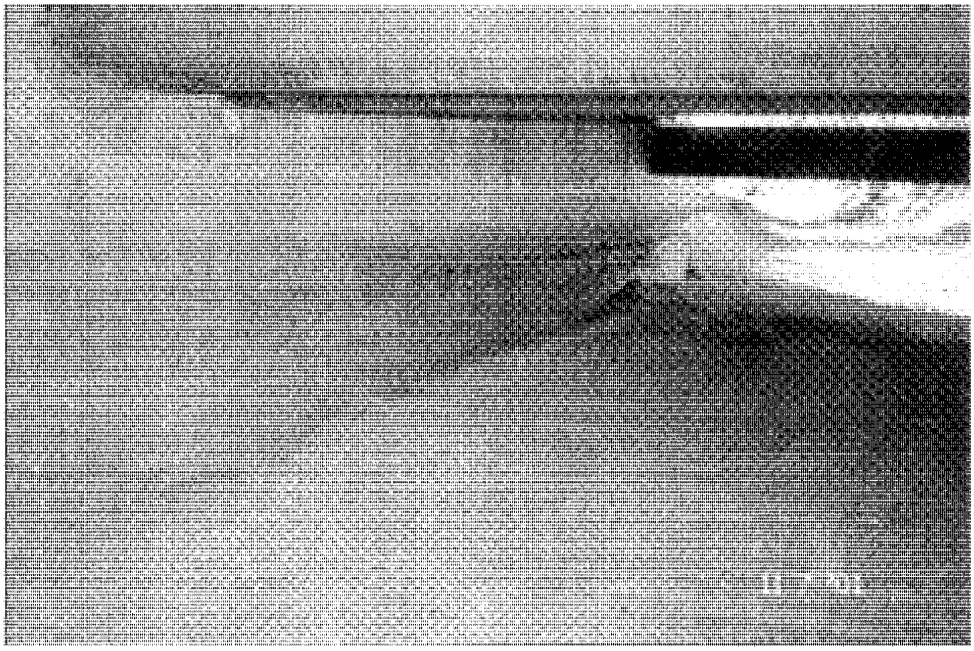


Photograph A-8.3.—View of grass growing on one of the bench areas. The grass roots have not penetrated the grout mattress.

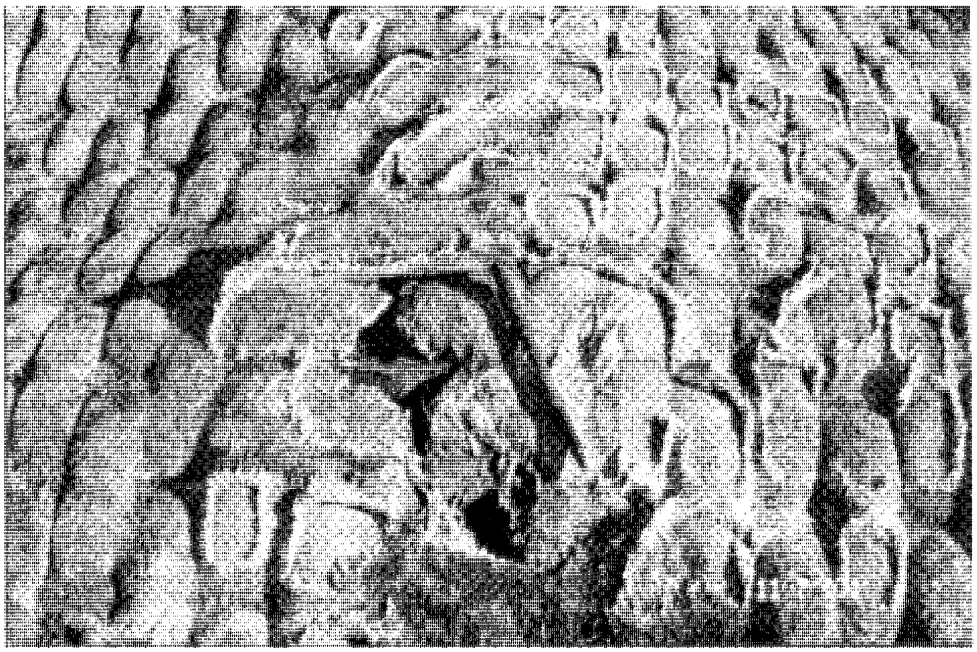


Photograph A-8.4.—View of 3 by 5 foot area where grout was missing between the mattress.

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



Photograph A-8.5.—Material that is still in good contact with the bridge abutments.



Photograph A-8.6.—Weathered mattress material and a small hole.

Test Section A-9 and A-10—

Material:	Test Section A-9 is 60-mil VLDPE with a 12-ounce geotextile cushion and a 3-inch grout-filled mattress on the side slopes only. Test Section A-10 is a 60-mil HDPE with a 12-ounce geotextile cushion and a 3-inch grout-filled mattress on the 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-ounce, needle-punched, nonwoven geotextile). The grout-filled mattress is Nicolon Armorform.
Construction Cost:	$1.79 per ft^2
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 beginning with 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 determined. Volcanic gases or velocity uplift are possible causes.
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 the District's request.
Photographs:	None

North Unit Irrigation District—Main Canal

Of the nine North Unit test sections, four failed in the first few years of service (two in the first year), and five are still in service and performing well. Figure 7 shows the location of the test sections. Visual inspections were performed in spring 2002.

Test Section 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 a ½ inch of 5-pound foam. Total protective coating thickness is 50 to 55 mils.
Construction Cost:	\$4.33 per ft^2, NU-1 \$3.92 per ft^2, NU-2
Date Installed:	October 1992 through March 1993 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:	Failed - During the first couple of irrigation seasons, large sections of foam began washing out in the invert. By Year 5, about half the foam had washed out, and the two test sections were removed from study.
	Removed from study - Replaced with RCC in the invert (1998) and Shotcrete on the side slopes (1999).

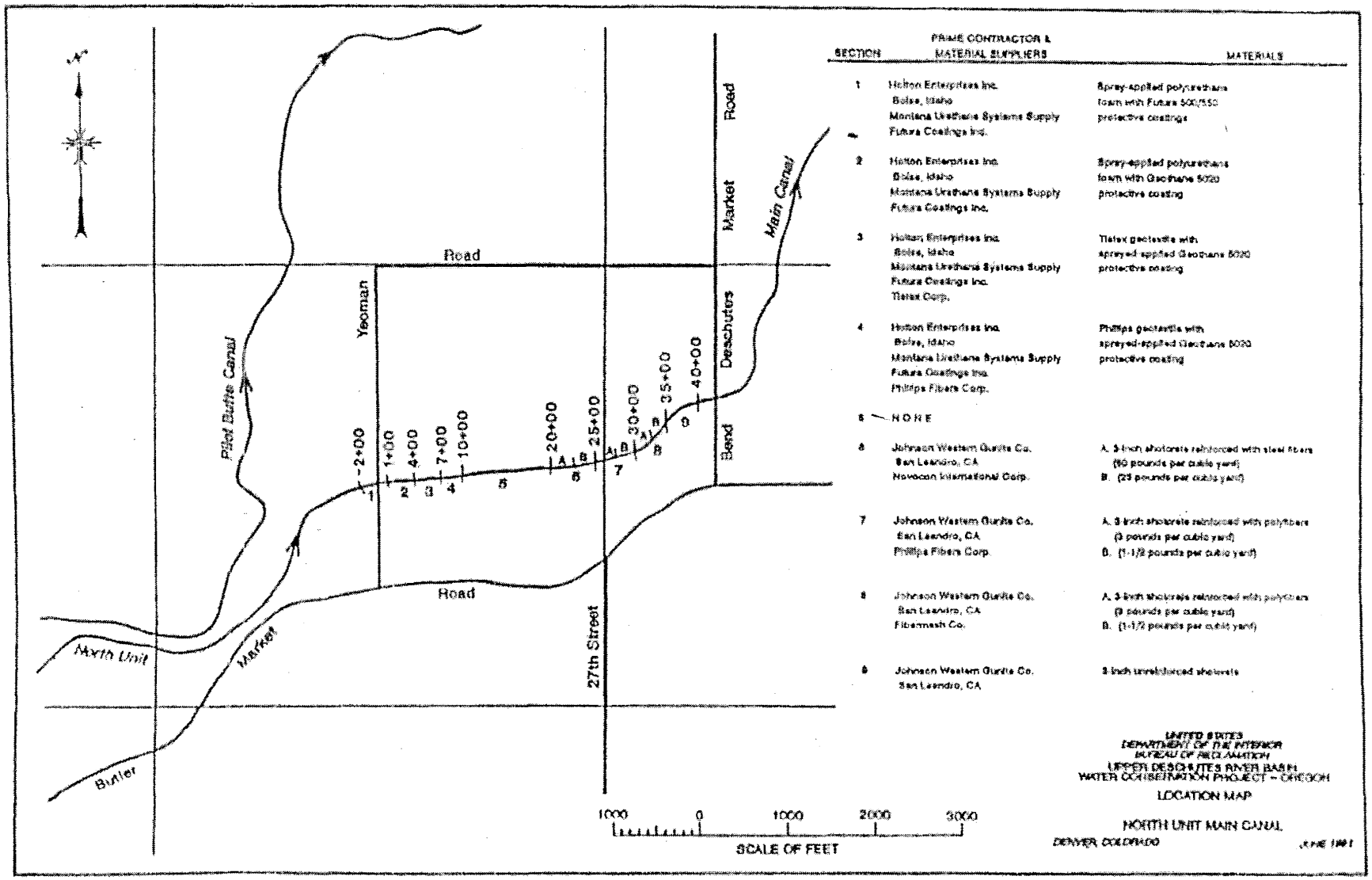


Figure 7.—North Unit Main Canal location map.

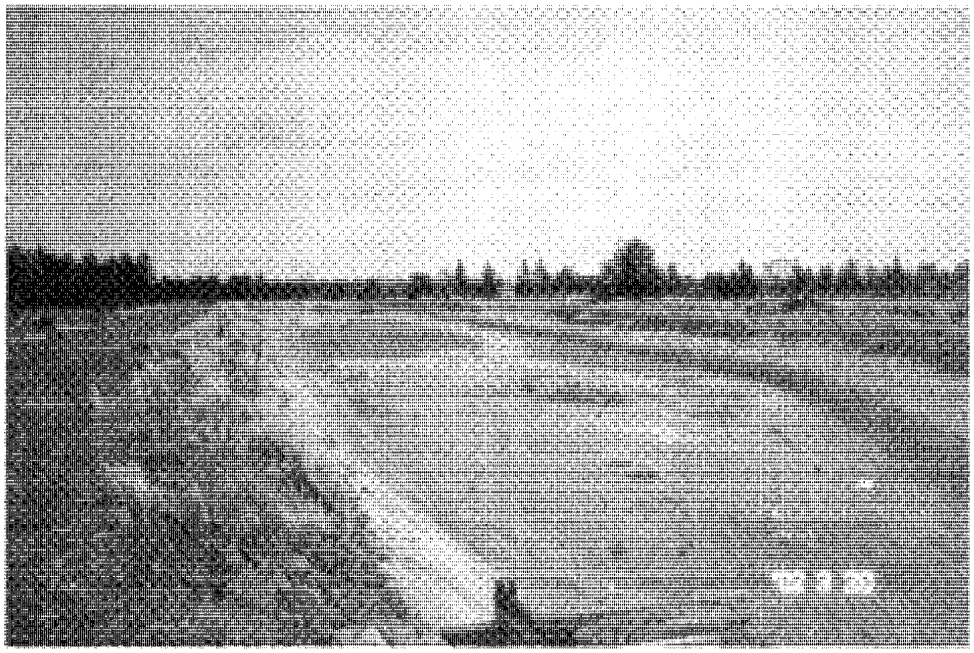
Test Sections NU-3 and NU-4—

Material:	Tietex geotextile with spray-applied Geothane 5020 membrane Phillips geotextile with spray-applied Geothane 5020 membrane
Description:	Tietex is a 6-ounce woven geotextile. Phillips Roof-on E-6N is a 6-ounce needle-punched, nonwoven geotextile. The total protective coating thickness is 60 mils.
Construction Cost:	\$2.64 per ft^2
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:	Failed - 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. Several large sections of geotextile washed downstream, damaging a pipeline crossing. The irrigation district removed all remaining liner in these two test sections. Removed from study - Both test sections were replaced with RCC invert (1998) and Shotcrete side slopes (1999).
Photographs:	None

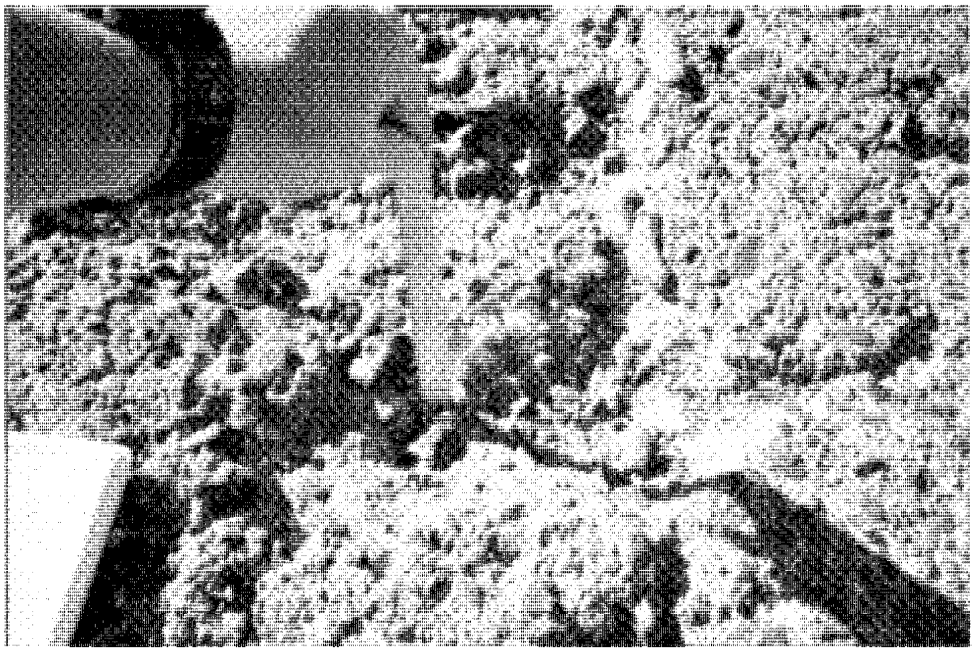
Test Section N-5—

Material:	Roller-compacted concrete (RCC) invert with Shotcrete side slopes
Description:	The canal invert has an average of 6 inches of polyfiber reinforced 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.
Construction Cost:	\$1.74 per ft^2 RCC Invert (based on actual bid price) \$2.49 per ft^2 Shotcrete Side slopes (based on actual bid prices) \$2.00 per ft^2 combined (40-foot invert with 10-foot side slopes)
Date installed:	March 1998 - RCC invert (4 years old) March 1999 - Shotcrete side slopes (3 years old)
Location:	North Unit Irrigation District (3.6 million square feet) RCC invert (12 miles; 2.2 million square feet) Shotcrete side slopes (7 miles; 1.4 million square feet)
Condition:	Very good to excellent - The Shotcrete side slopes are in excellent condition after 3 years of service with no cracking. The RCC invert was in very good condition after 4 years of service. The RCC invert had deteriorated in several locations where the RCC is being eroded away by the high-velocity water flows. This erosion is occurring only where dozer tracks are visible in the RCC. In some areas, the concrete had eroded 4 inches deep and continues to erode. The District has patched the worst areas, areas where the RCC had eroded 4 to 6 inches. Patching consisted of pumping ready-mix concrete into the invert and blading smooth with a front end loader bucket. The long-term durability of these repairs will depend on their ability to bond to the existing RCC. Other areas which were rolled completely smooth (no visible dozer tracks) were holding up well, and there was no erosion of the RCC.
Maintenance:	Minimal to date Performed: Patched eroded dozer tracks in RCC. Needed: Additional eroded dozer tracks in RCC need to be patched.
Photographs:	1 through 3

North Unit Canal - Test Section NU-5
Roller-Compacted Concrete (RCC) Invert with Shotcrete Side Slopes

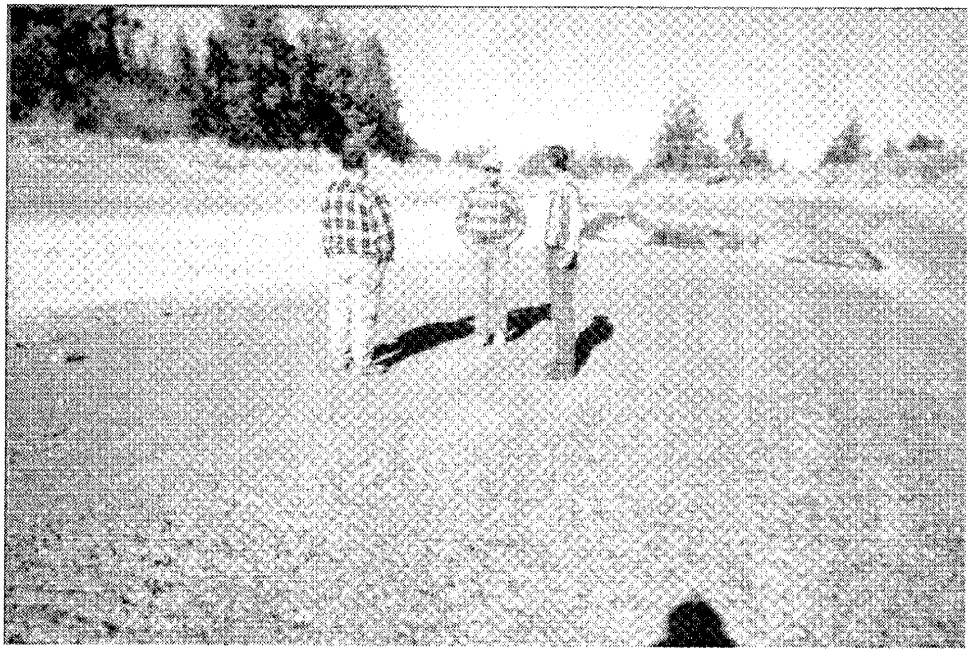


Photograph NU-5.1.—Overview of the North Unit Canal Test Section NU-5, which is in very good condition.



Photograph NU-5.2.—Close-up view of water erosion of roller-compacted concrete in the bottom of the canal.

North Unit Canal - Test Section NU-5
Roller-Compacted Concrete (RCC) Invert with Shotcrete Side Slopes



Photograph NU-5.3.—Standing on smooth area of thin patch mix that was spread using the back of a dozer blade.

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 probably averages about 5 inches.

Date Installed: February 1992 (10 years old)

Condition: Excellent - All the Shotcrete was in excellent condition after 10 years of service. No obvious visible differences existed in the performance of the four Shotcrete test sections. No freeze-thaw damage was evident. A large pond just upstream from the drop structure (station 27+80) indicated a low seepage rate. Small ponds were present on all four test sections.

Contraction cracks on the sidewalls had developed every 100 to 200 feet. Crack width varied from hairline to 1/8 inch. Cracks did not extend completely across the canal prism, but instead usually disappeared somewhere in the sidewall or invert. Cracks were more evident during cold weather. Cracks grew in length and numbers with time, but did not seem to widen significantly. Vegetation was growing out of cracks in the Shotcrete near the top of side slopes.

Some small irregular voids (holes) were found in the Shotcrete up to 4 inches in depth. Several partially exposed rocks were discovered with little or no Shotcrete cover.

The thickness of the Shotcrete was variable because of the irregular surface and the normal problems with field-installation quality control. A few small holes (up to 2 feet in diameter) had developed and had been patched. At these locations, the Shotcrete was found to be very thin (less than 1 inch). More holes continue to develop in thin areas.

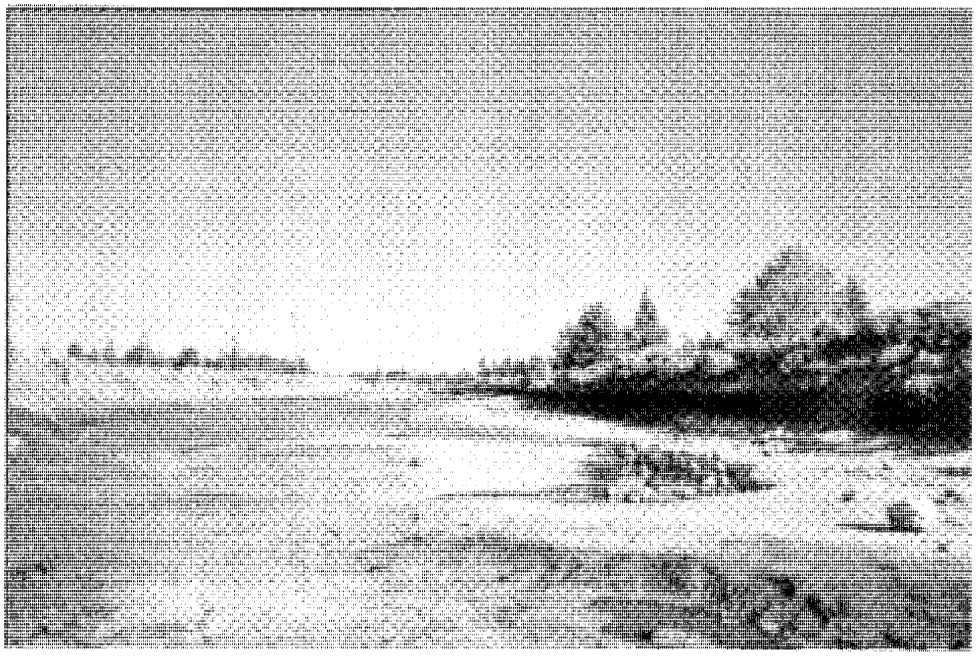
The areas where the flow prism was constricted and where the velocity increased showed a small amount of exposed aggregate in the invert that was the result of erosion of the surface cement. This erosion does not appear to be a problem.

The Shotcrete surfacing is attracting local kayakers to this section of canal. The kayakers have been observed rolling large rocks (12 to 24 inches in diameter) into the canal to increase turbulence at selected locations.

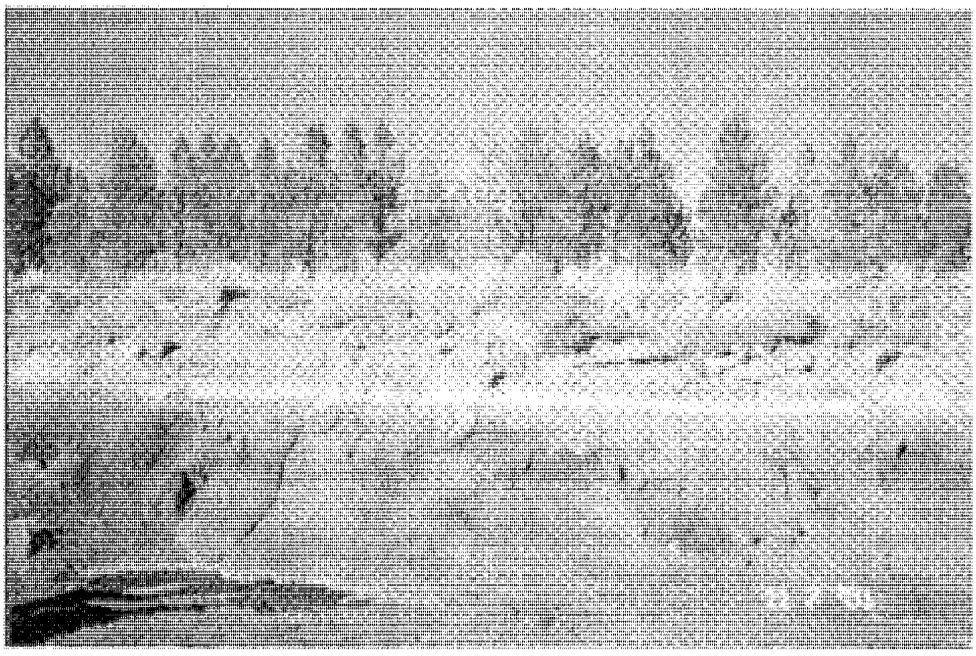
Test Section NU-6—

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 (10 years old)
Location:	Station 20+00 to 25+00 (500 linear feet, 30,000 square feet)
Condition:	Excellent - The shotcrete was performing well after 10 years of service. This test section had some cracking, exposed subgrade rocks, and vegetation typical of all the Shotcrete test sections. This test section also had some serious voids on the left bank that were caused by deficiencies in the original construction. For a couple hundred feet on the left bank, the contractor brought in soil to fill voids in the irregular subgrade before shotcreting. However, the imported silty material is washing out, creating voids under the shotcrete surface. Several large voids (up to 10 feet in diameter) had developed under the Shotcrete. Holes developed in the Shotcrete where it was unsupported and very thin (typically less than 1 inch). Steel fibers, visible on the Shotcrete surface, were corroded, rust-brown in color, and very weak (easily broken 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-foot section which contains 50 pounds of steel fibers per cubic yard of Shotcrete and the second 250-foot section which contains 25 pounds of steel fibers per cubic yard of Shotcrete.
Maintenance:	Minimal maintenance has been required. Performed: As part of routine maintenance, the District has patched a couple of small holes (1 to 2 feet in diameter) in the shotcrete. The District has also sealed about 60 feet of transverse cracks with elastomeric sealant. Repair of the large voids on the left bank is considered special maintenance related to deficiencies in the original construction. The District has repaired a couple of large voids that developed on the left bank where the contractor backfilled with silty soil. Several yards of concrete were pumped into these voids. Voids continue to develop in this area. This special maintenance is not included in the maintenance evaluation for this test section. Needed: Several small holes in the Shotcrete lining need to be patched. Also, a couple of large voids on the left bank need to be filled with pumped concrete.
Photographs:	1 through 4

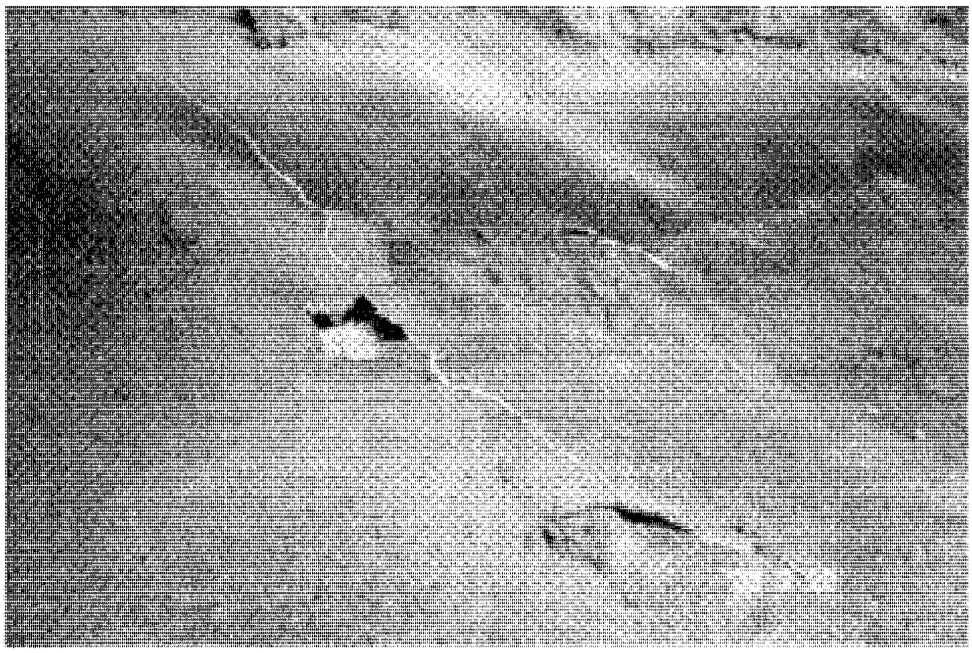
North Unit Canal - Test Section NU-6
Shotcrete reinforced with Novocon steel fibers



Photograph NU-6.1.—Overview of the North Unit Canal Test Section NU-6, which is in excellent condition.



Photograph NU-6.2.—View of north side wall where concrete was pumped into voids beneath shotcrete lining.



Photograph NU-6.3.—Hole that developed where shotcrete was not 3 inches thick.

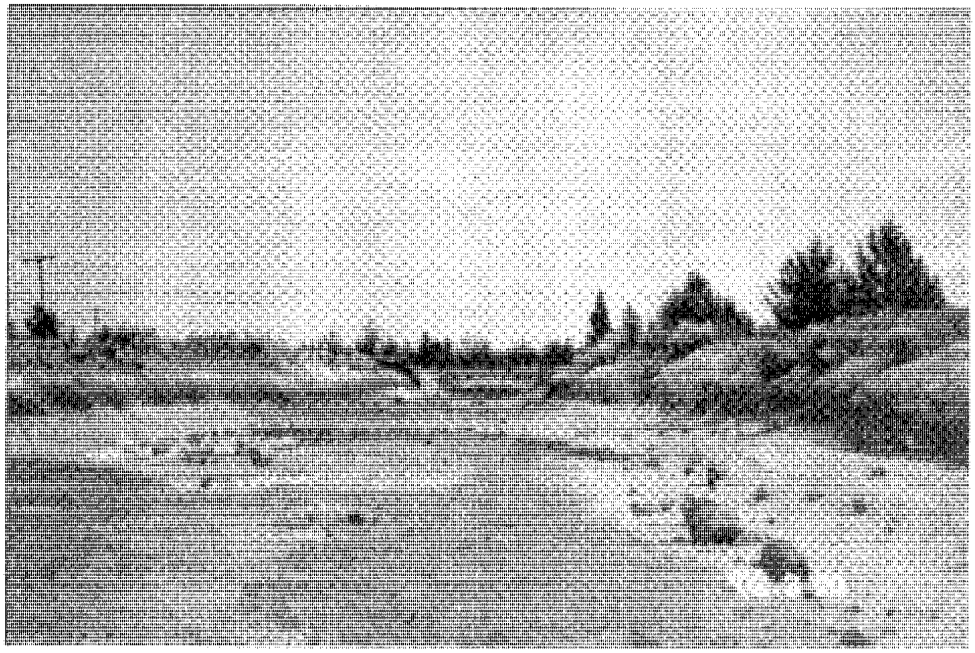


Photograph NU-6.4.—View of lateral cracking on side walls.

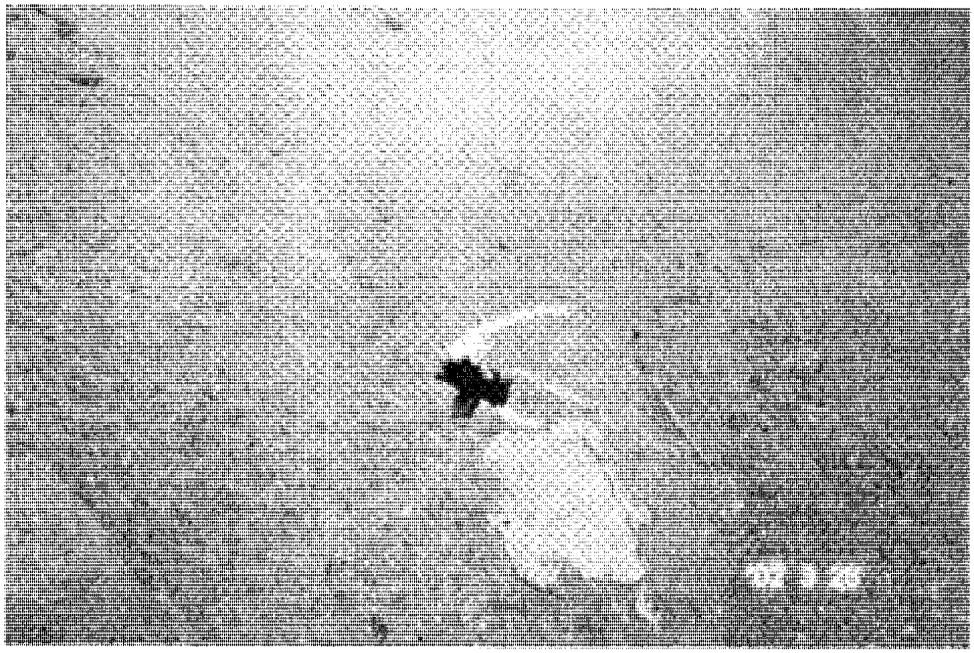
Test Section NU-7—

Material:	Shotcrete reinforced with Phillips polyfibers
Description:	Polyfibers are ¾-inch Phillips Fi-con polypropylene fibers
Construction Cost:	\$2.21 per ft^2 at fiber dosage of 1½ lb/yd^3 \$2.14 per ft^2 at fiber dosage of 3 lb/yd^3
Date Installed:	February 1992 (10 years old)
Location:	Station 25+00 to 30+00 (500 linear feet; 30,000 square feet)
Condition:	Excellent - The Shotcrete was performing well after 10 years of service. The test section has some minor cracking, small 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, which contains 3 pounds of polyfibers per cubic yard of Shotcrete and the second 250-foot section which contains 1.5 pounds per cubic yard. A few subgrade rocks were exposed at the flume, where water velocities are high.
Maintenance:	Minimal maintenance required to date Performed: The District has patched some small holes (1to 2 feet in diameter) with sack-mix concrete Needed: No maintenance required at this time. The District will continue to patch small holes as they develop.
Photographs:	1 and 2

North Unit Canal - Test Section NU-7
Shotcrete reinforced with Phillips polyfibers



Photograph NU-7.1.—Overview of the North Unit Canal Test Section NU-7, which is in excellent condition.

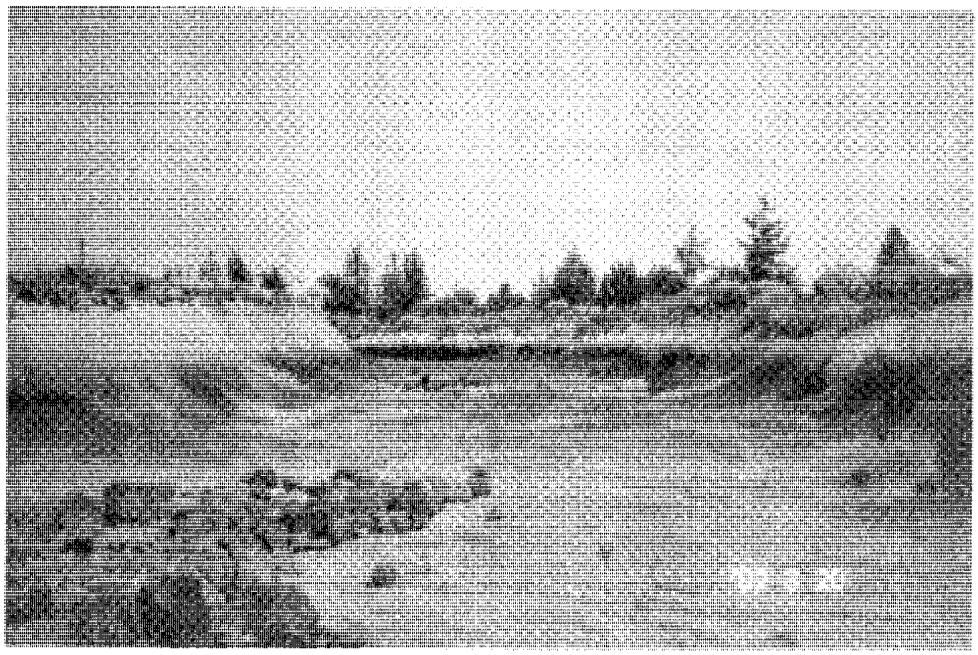


Photograph NU-7.2.—View of old repair made during the second year and new hole above patch.

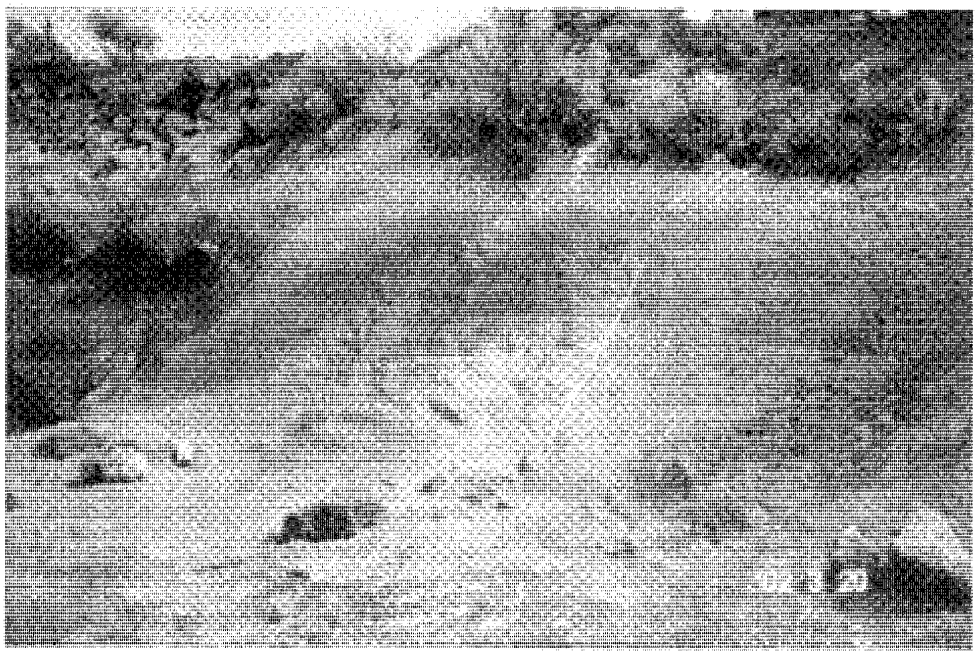
Test Section NU-8—

Material:	Shotcrete reinforced with Fibermesh polyfibers
Description:	Polyfibers are Fibermesh Harbourite 320 (3/4-inch-long fibrillated polypropylene fibers).
Construction Cost:	\$2.21 per ft^2 at a fiber dosage of 1½ lb/yd^3 \$2.14 per ft^2 at a fiber dosage of 3 lb/yd^3
Date Installed:	February 1992 (10 years old)
Location:	Station 30+00 to 35+00 (500 linear feet, 30,000 square feet)
Condition:	Excellent - The Shotcrete was performing well after 10 years of service. The test section had some minor cracking, exposed subgrade rocks, and vegetation typical of all Shotcrete installations. Polyfibers are visible on the Shotcrete surface. No visible 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, containing 1.5 pounds per cubic yard.
Maintenance:	Minimal maintenance required to date Performed: In 2000, the District replaced some calking on the right bank. The calking was in excellent condition at the time of the inspection. Kayakers installed some hand-holds and eye bolts on the left bank, which were removed, and the damage was repaired by the District. Needed: None
Photographs:	1 and 2

North Unit Canal - Test Section NU-8
Shotcrete reinforced with Fibermesh polyfibers



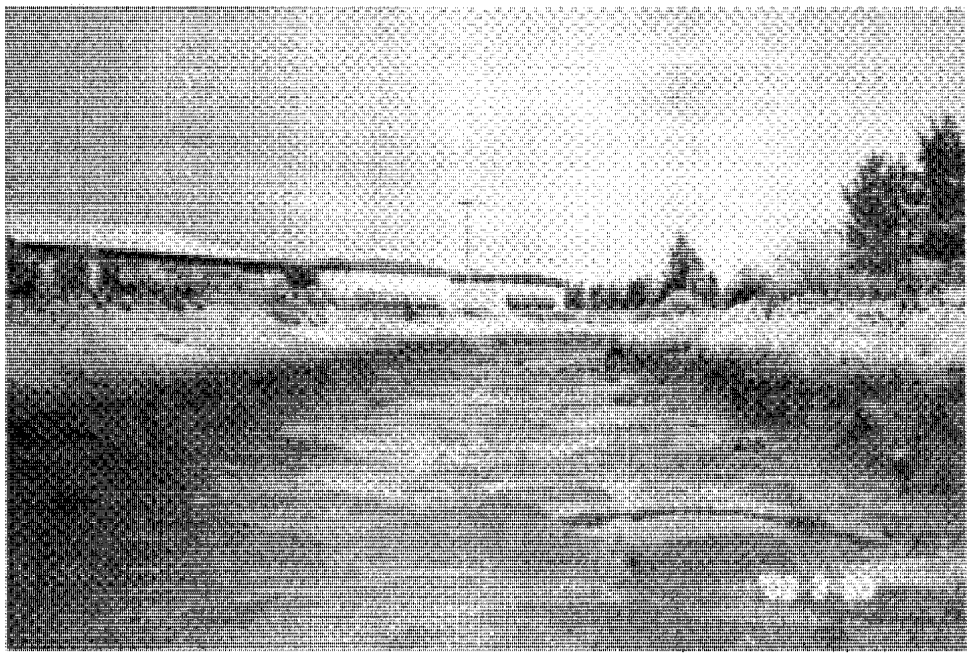
Photograph NU-8.1.—Overview of the North Unit Canal Test Section NU-8, which is in excellent condition.



Photograph NU-8.2.—View of horizontal and vertical cracking on side wall.

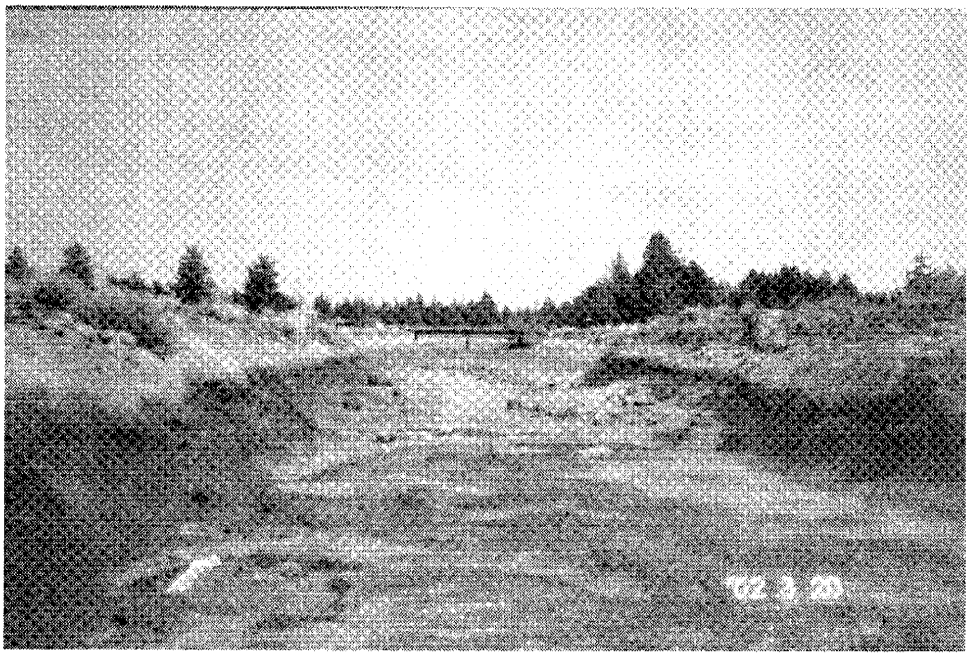
Test Section NU-9—

Material:	Unreinforced Shotcrete
Construction Cost:	$2.07 per ft^2
Date Installed:	February 1992 (10 years old)
Location:	Station 35+00 to 40+00 (500 linear feet; 30,000 square feet)
Condition:	Excellent - The Shotcrete was performing well after 10 years of service.
	The test section had some minor cracking, exposed subgrade rocks, and vegetation typical of all the shotcrete installations.
Maintenance:	Minimal maintenance required to date.
	Performed: In 2000, the District patched a couple of small holes at the downstream end.
	Needed: None. District will continue to patch small holes as they develop.
Photographs:	1 through 3

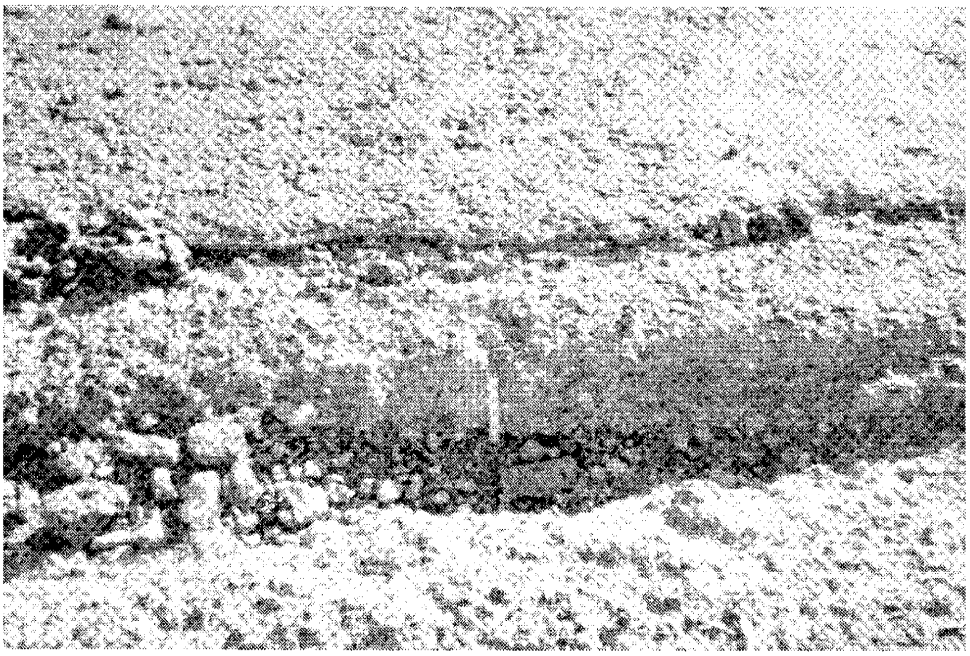


Photograph NU-9.1.—Overview of the North Unit Canal Test Section NU-9, which is in excellent condition.

North Unit Canal - Test Section NU-9
Unreinforced Shotcrete



Photograph NU-9.2.—View of the canal at the end of the test section.



Photograph NU-9.3.—View of offset in the Shotcrete where the roller-compacted concrete and the test section come together.

Tumalo Irrigation District—Bend Feed Canal

Test Section T-1—

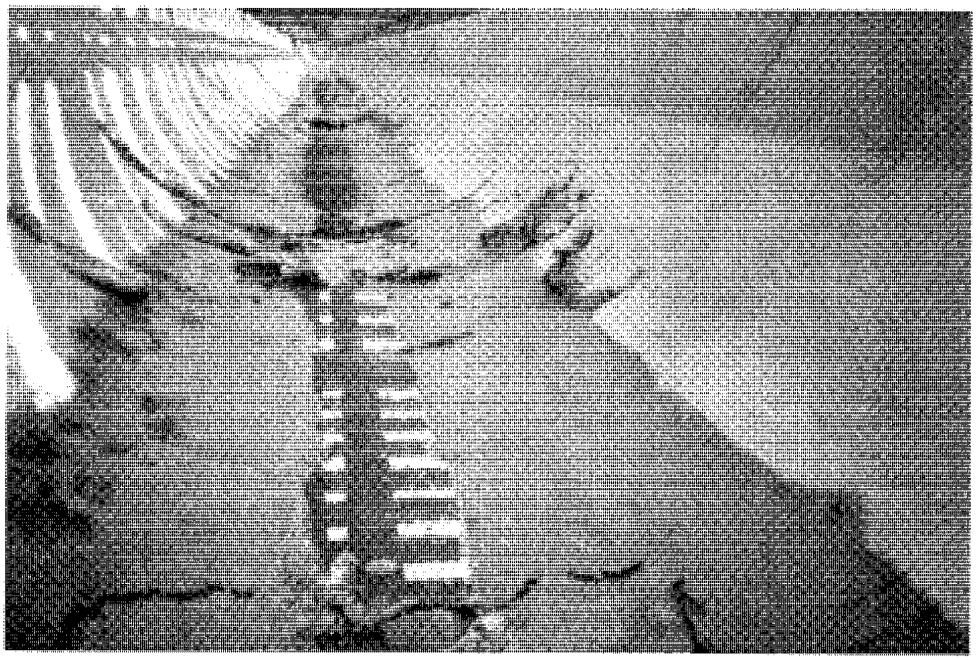
Material:	Liquid Boot over an existing concrete flume
Description:	Liquid Boot is a spray-applied neoprene-polymer-modified asphalt emulsion.
Construction Cost:	$1.70 per ft^2
Date installed:	April 1994 (After 5 years, replaced with buried pipe - April 1999)
Location:	Bend Feed Canal Headworks (75 linear feet; 1,575 square feet)
Condition:	The Liquid Boot was completely disbonded from the 11-foot invert and most had 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 were identified that might have increased the likelihood for success of this test section. A cut-off 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 has been required to date.
Photographs:	None

Test Section T-2—

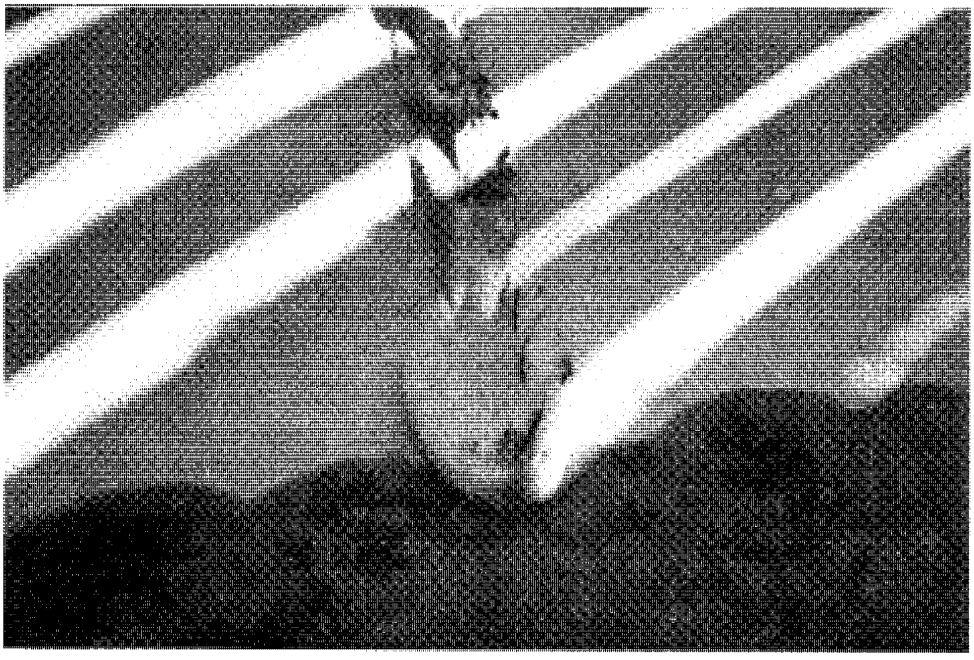
Material:	Liquid Boot over a sandblasted steel flume
Description:	Liquid Boot is a spray-applied neoprene-polymer-modified asphalt emulsion.
Construction Cost:	$2.16 per ft^2
Date installed:	April 1994 (After 8 years, replaced with steel siphon - October 2001)
Location:	Flume #4 - Bend Feed Canal (463 linear feet; 7,871 square feet)
Condition:	Very good - Although the test section was replaced after 8 years with a steel siphon, the Liquid Boot was still in good condition and many years of service life remaining . The Liquid Boot was well bonded to 90 percent of the steel flume. Several small leaks had developed over the last couple years. These leaks were in various stages, from drips every few minutes to small, continuous flow. One of the larger leaks was suspected to be caused by a shift in the metal panels. The number of blisters (50+) has remained unchanged. Most of the blisters in the Liquid Boot were directly over the old tar material in the seams between the flume's 3-foot-wide steel panels. Most of the blisters were in the bottom of the invert, with just a couple 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 was not completely bonded to the old tar material, and the Liquid Boot deformed and blistered under the force of the flowing water. Once a small hole developed in the blister, the flowing water deposited sand and debris, causing the blister to grow in size. 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 clean-out drain was partially disbonded but in fair condition. The Liquid Boot had 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 Polyol 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:	Moderate maintenance has been required. Minor maintenance would have been required if the flume had not been replaced with a steel siphon in October 2001. The District had been patching blisters with a single-part roofing tar, which it reports is much easier to use than the 2-part Liquid Boot Trowel Grade with equivalent performance.
Photographs:	1 through 6

Tumalo Irrigation District - Test Section T-2
Liquid Boot over a sandblasted steel flume

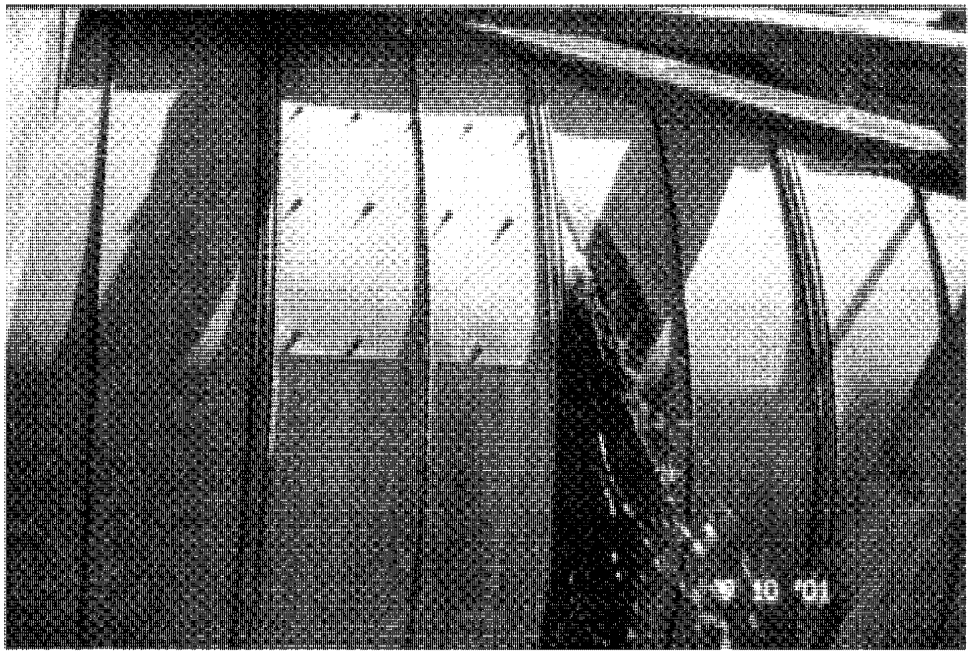


Photograph T-2.1.—Overview of the Tumalo Flume Test Section T-2, which is in very good condition. Note some blistering in the invert of the flume. This is occurring only in last 100 feet of the downstream end.

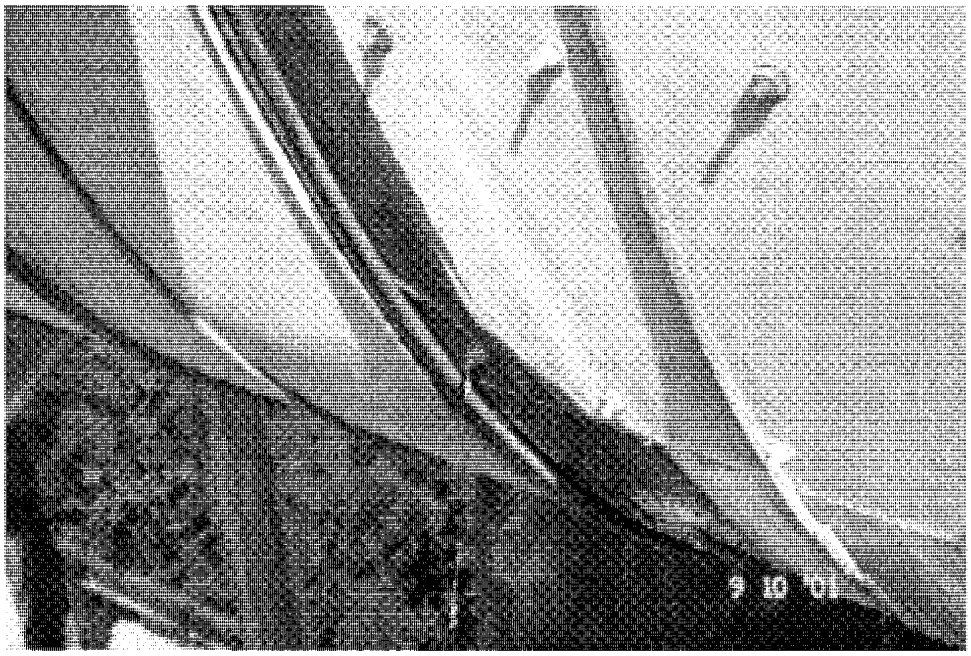


Photograph T-2.2.—View of a blister that filled with sand at one of the joints on the side slope.

Tumalo Irrigation District - Test Section T-2
Liquid Boot over a sandblasted steel flume

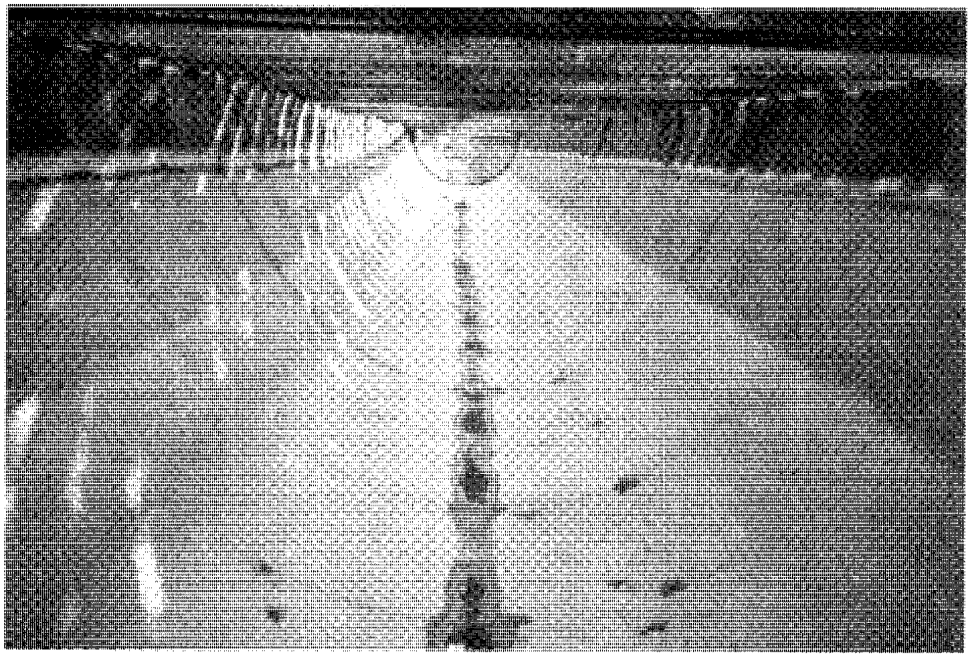


Photograph T-2.3.—View of a large leak in the steel flume. Although some blistering is at this point, it is suspected that movement of the steel section maybe the bigger cause of this leak.

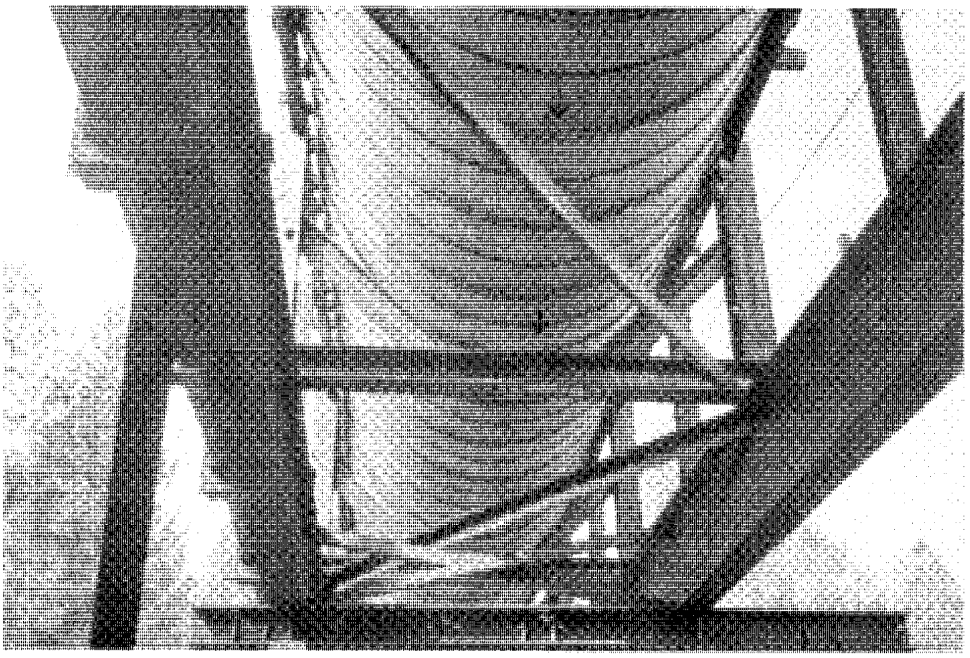


Photograph T-2.4.—View of another large leak in the flume.

Tumalo Irrigation District - Test Section T-2
Liquid Boot over a sandblasted steel flume



Photograph T-2.5.—View of the steel flume in the upstream area, where the flume is in excellent condition.



Photograph T-2.6.—View from under the flume in the upstream area. Note the dry areas where the leaks have been fixed.

Test Section T-3—

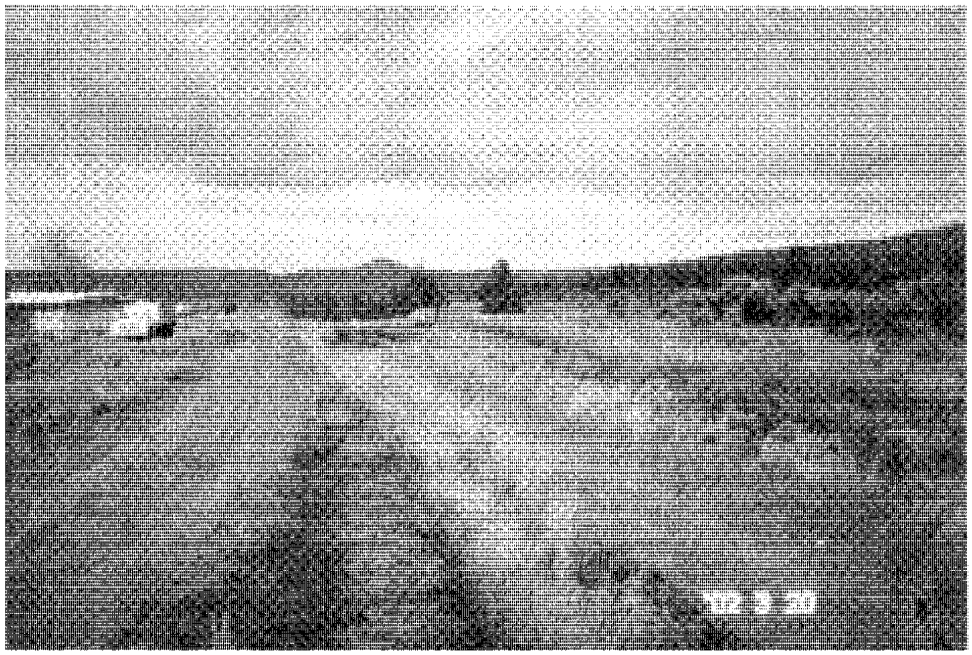
Material:	Liquid Boot over a broomed steel flume
Description:	Liquid Boot is a spray-applied neoprene-polymer-modified asphalt emulsion.
Construction Cost:	$1.40 per ft^2
Date installed:	April 1995 (Replaced with steel siphon after 5 years - April 2000)
Location:	Klippel Flume - Bend & Webber Canals (300 linear feet; 5,100 square feet)
Condition:	Very Good - Although replaced after 5 years with a steel siphon, the Liquid Boot was still in good condition and had many years of remaining service life. 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 water is still standing in much of the flume. Over 50 blisters have developed in the Liquid Boot, directly over the old tar material in the seams between the flume's 3-foot-wide steel panels. except for a couple located 1 to 2 feet up the side, most of the blisters are in the bottom of the invert. The blisters typically measure 6 inches across, and the largest measure 6 inches across by 12 inches long. The blisters are full of sand and sediment. Apparently, the Liquid Boot is not completely 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 cut off 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:	Moderate maintenance required to date. Minor maintenance would have been required at this time if the flume had not been replaced with a steel siphon in April 2000. To repair the boot, the District would have cut open the blisters, trimmed away any unbonded material, then patched with Liquid Boot Trowel Grade. The District has also been using a single-part roofing tar for minor repairs. They report the roofing tar is much easier to use than the 2-part Liquid Boot Trowel Grade, and the performance of the two is about equal.
Photographs:	None

Ochoco Irrigation District—Main Canal

Test Section O-1 and O-2—

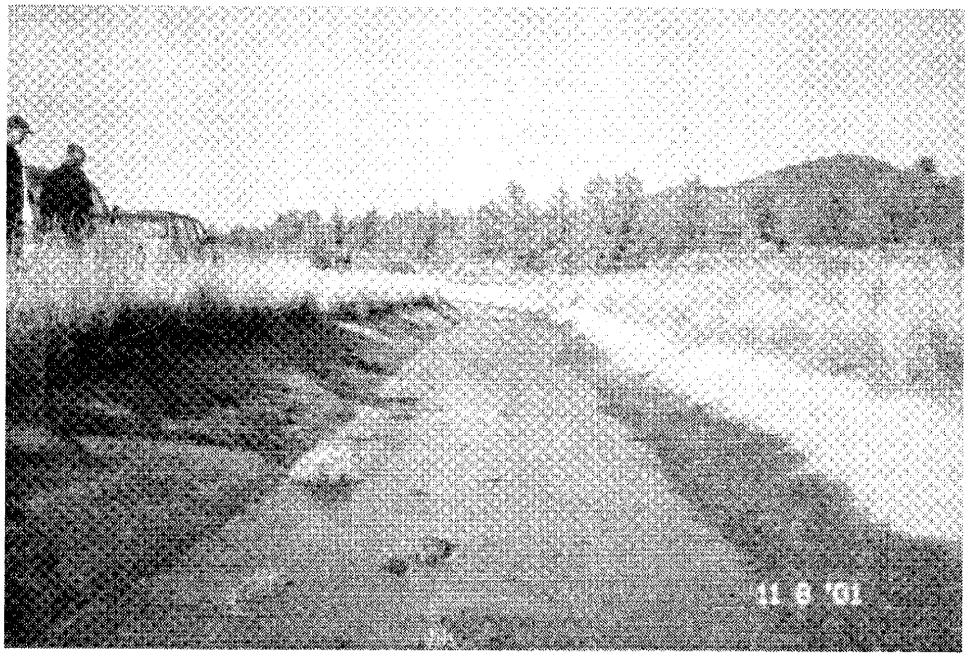
Material:	O-1a: Covered Bentomat DN Geosynthetic Clay Liner (GCL) O-1b: Covered Bentomat CL GCL O-2a: Exposed Bentomat DN GCL O-2b: Exposed Bentomat CL GCL
Description:	CETCO Bentomat DN is a reinforced GCL consisting of a layer of sodium bentonite encapsulated between two needle-punched non-woven geotextiles. Rolls measure 14 feet wide by 150 feet long. CETCO Bentomat CL is a reinforced GCL consisting of a layer of sodium bentonite encapsulated between a woven and a needle-punched, non-woven geotextile laminated to a thin geomembrane. Rolls measure 14½ feet wide by 150 feet long.
Construction Cost:	\$0.82 per ft^2 Covered Bentomat DN \$0.87 per ft^2 Covered Bentomat CL \$0.76 per ft^2 Exposed Bentomat DN \$0.81 per ft^2 Exposed Bentomat CL
Date installed:	April 1999 (3 years old)
Location:	Ochoco Irrigation District (1,245 linear feet; 50,000 square feet)
Condition:	Excellent where buried. The buried (covered) GCL is not accessible for visual assessment Very good where exposed. The exposed DN (double nonwoven) GCL is in very good condition after 3 years of service. Above the waterline on the north bank (southern exposure), the exposed DN GCL is exhibiting areas of surface cracking. The depth of this cracking is unknown. The GCL does not show any surface cracking below the waterline or above the waterline where covered with just a light dusting of dirt. Grass is growing in the top layer of the GCL geotextile at the waterline. Some scattered grass is growing in other places above the waterline and may fill in over the next few years. The exposed CL (thin geomembrane on back side) GCL is also in very good condition after 3 years of service. Above the waterline on the north bank (southern exposure), the exposed CL GCL is exhibiting areas of surface cracking. The depth of this cracking is unknown. The GCL does not show any surface cracking below the waterline or above the waterline where covered with just a light dusting of dirt. Many of the seams have a tuft of grass growing immediately downstream from the seam at the waterline. Again, the grass is rooted in the top layer of geotextile. On the north bank (southern exposure), the GCL has shrunk about 1 inch longitudinally, and the seams have curled upward because of the difference in shrinkage or thermal expansion between the GCL and the thin geomembrane on the backside.

Construction Note:	The GCL manufacturer (CETCO) recommends at least 1 foot of cover soil to provide a confining pressure and to protect the GCL. However, the seepage requirement for irrigation canals is much less stringent than for other GCL applications (e.g., landfills and sewage lagoons). Therefore, these experimental exposed test sections were constructed to evaluate the cost savings of eliminating the cover material.
Maintenance:	Additional stakes are needed to secure curling seams in the exposed CL. Because the exposed GCL's are beginning to deteriorate, the District will cover them with native soils to prevent additional degradation.
Photographs:	1 through 7

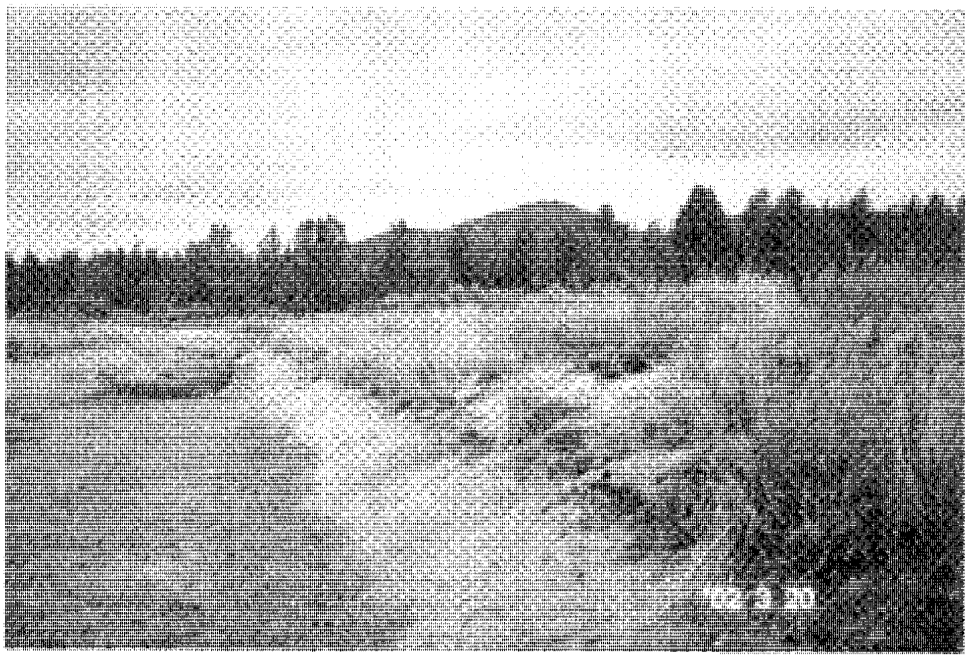


Photograph O-1.1.—Overview of the buried areas of the Ochoco Canal Test Sections O-1a and O-1b, which are in excellent condition.

Ochoco Irrigation District - Test Section O-1 and O-2
Covered Bentomat DN Geosynthetic Clay Liner (GCL) and Exposed GCL



Photograph O-2.2.—Overview of the exposed areas of the Ochoco Canal Test Sections O-2a and O-2b, which are in very good condition.

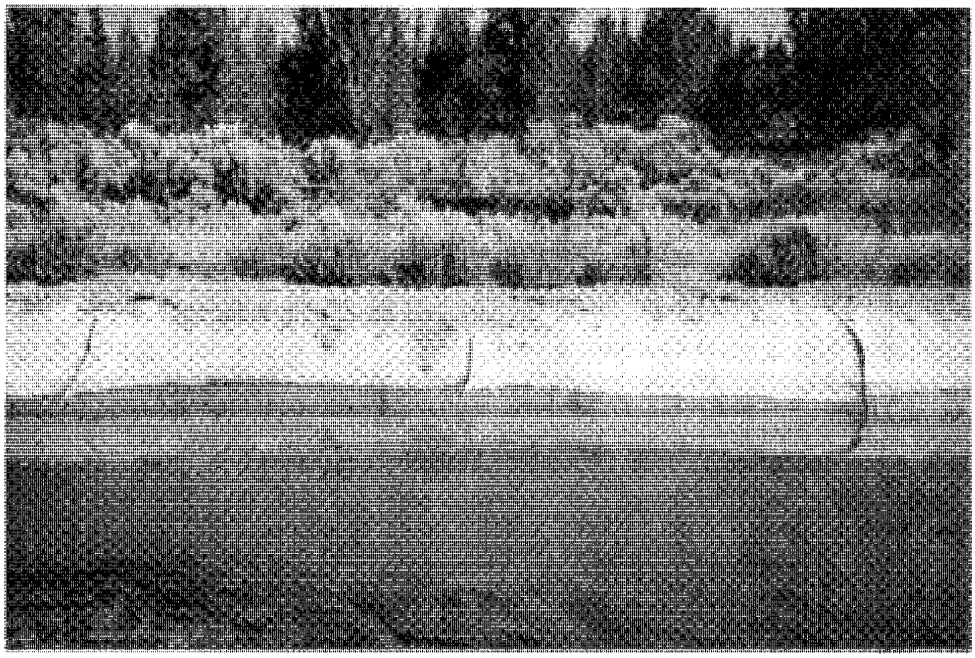


Photograph O-2.3.—View of test section O-2a Type DN GCL. Note cracking and grass growing through the GCL.

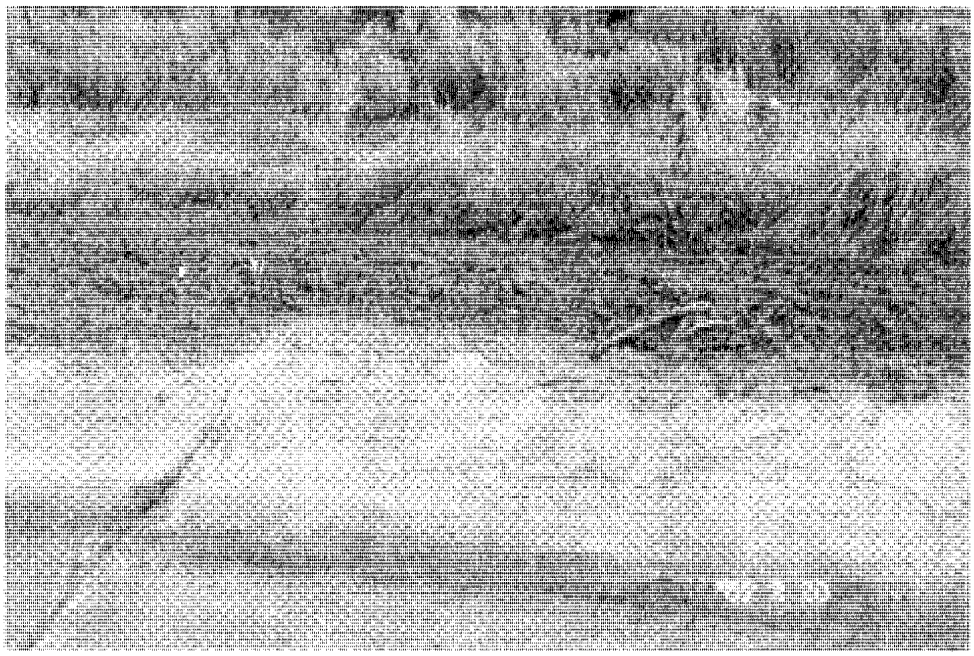
Ochoco Irrigation District - Test Section O-1 and O-2
Covered Bentomat DN Geosynthetic Clay Liner (GCL) and Exposed GCL



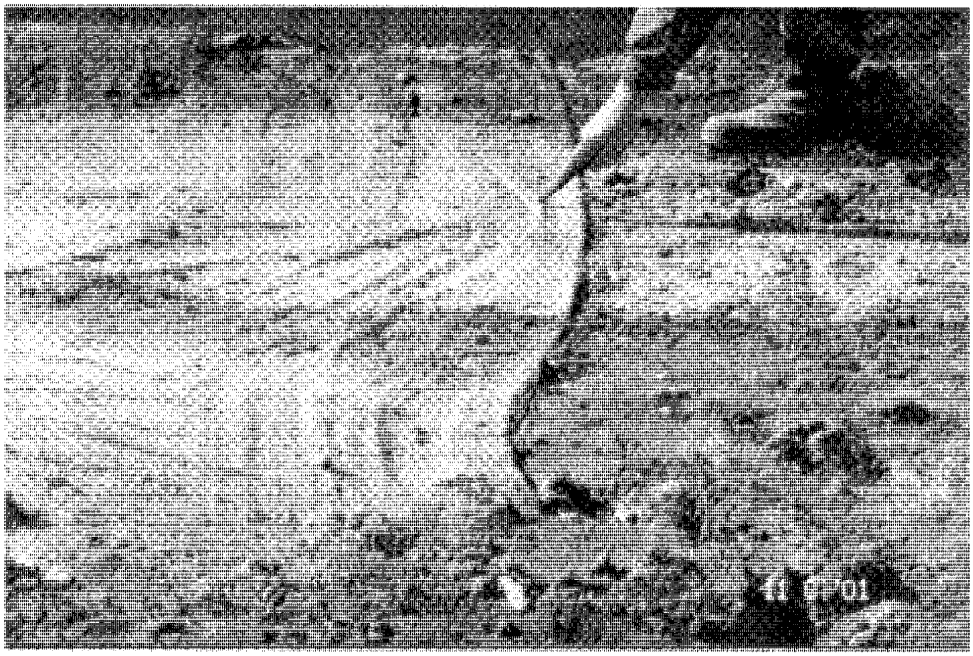
Photograph O-2.4.—Overview of test section O-2b Type CL GCL. This section is downstream from section O-2a and is in very good condition.



Photograph O-2.5.—View looking at the north side of the canal (sun side). Cracking can be seen in the panel on the right side of the photograph. The panel on the left, which has very little dirt on top has no cracks.



Photograph O-2.6.—View of cracking on the top near the anchor trench.

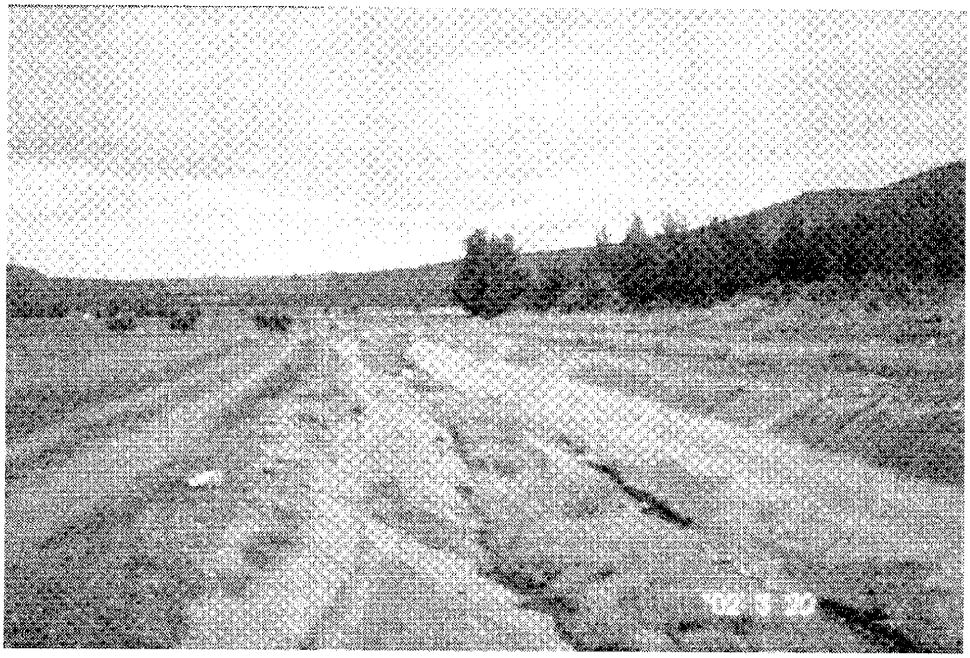


Photograph O-2.7.—View of the GCL shrinking at the overlap, where exposed. This seems to be occurring area more frequently in the CL test section.

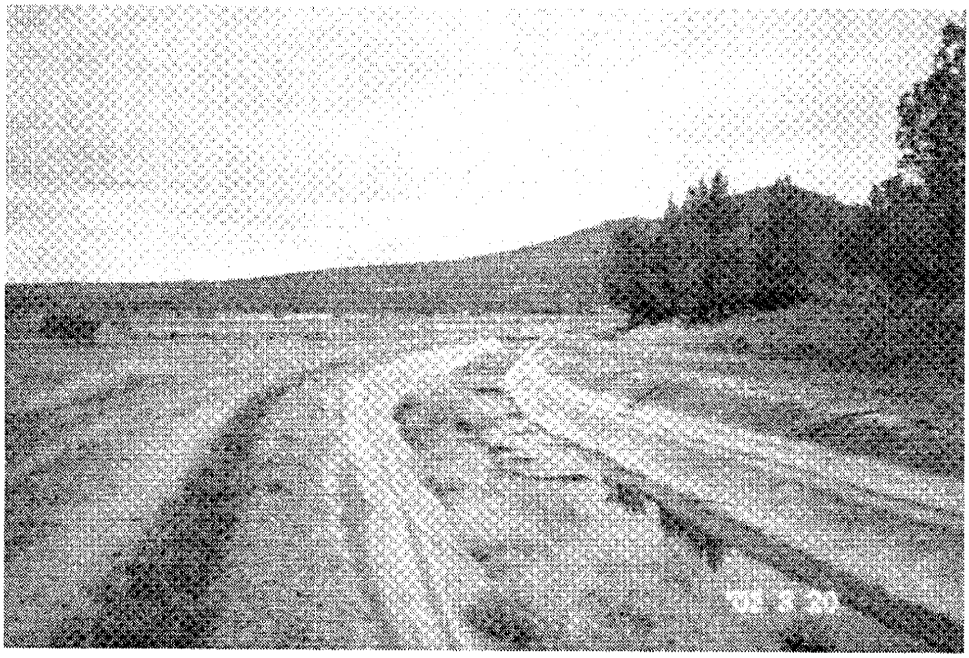
Test Section O-3a and O-3b—

Material:	O-3a: Exposed 45-mil EPDM with geotextile cushion on side slopes O-3b: Exposed 45-mil EPDM with geotextile cushion on side slopes and covered invert
Description:	Firestone PondGard is 45-mil unreinforced EPDM (ethylene propylene diene monomer) rubber. The geotextile cushion on the side slopes is 8-oz, needle-punched nonwoven (LP-8), supplied by Layfield Plastics.
Construction Cost:	\$0.84 per ft^2 for O-3a \$0.87 per ft^2 O-3b
Date installed:	November 1999 (2½ years old)
Location:	Ochoco Irrigation District (1,530 linear feet; 63,000 square feet)
Condition:	Excellent - The exposed EPDM is in excellent condition after 2 years of service. Water flow has distributed the invert soil and sediment so that the two test sections now look the same. Both test sections have about 2 inches of cover soil (or sediment) in the invert. The factory and field seams are in excellent condition. Numerous animal tracks (mostly deer) are visible, but animals have not caused any damage. The backhoe operator reportedly tore a small hole in the EPDM while removing the dike between the two test sections. The tear is reportedly at the left groin, where the side slope meets the invert, but it could not be found because of residual dike material. Sample - In November 2001, a 16- by 24-inch sample was taken for laboratory testing. The liner was repaired with an EPDM patch and EPDM glue. Before patching, the EPDM liner was cleaned with liquid detergent and a scrub brush.
Maintenance:	None required to date. If flowing water washes away the remnants of the earthen dike and exposes the tear at the groin, the district will need to repair the tear with an EPDM patch and EPDM glue.
Photographs:	1 through 3

Ochoco Irrigation District - Test Section O-3a and O-3b
Exposed 45-mil EPDM with geotextile cushion on side slopes

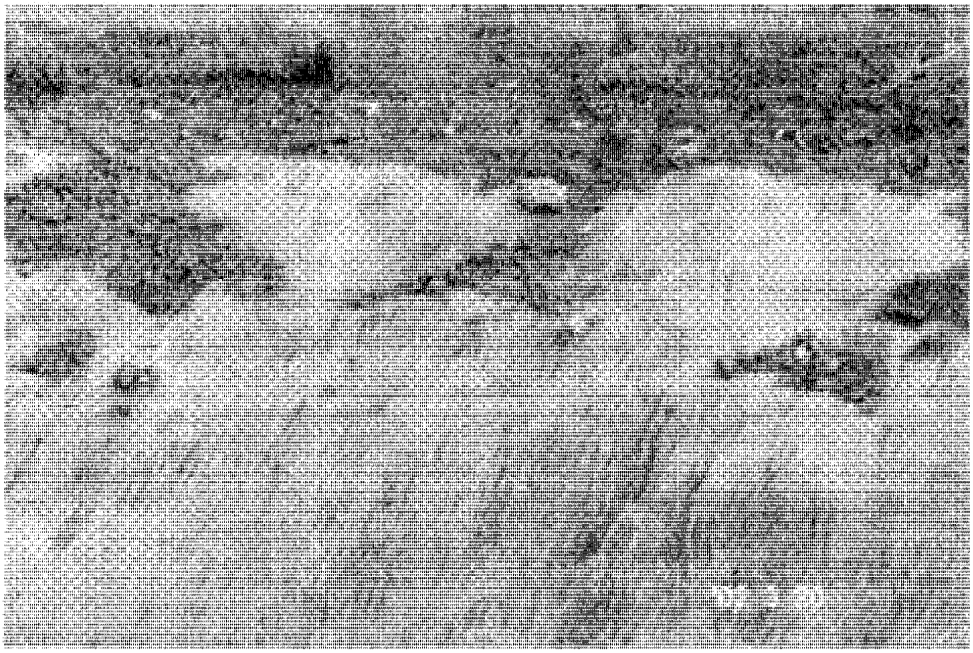


Photograph O-3.1.—Overview of the Ochoco Canal Test Section O-3a (exposed invert), which is in excellent condition.



Photograph O-3.2.—Overview of the Ochoco Canal Test Sections 3b (buried invert), which is in excellent condition.

Ochoco Irrigation District - Test Section O-3a and O-3b
Exposed 45-mil EPDM with geotextile cushion on side slopes

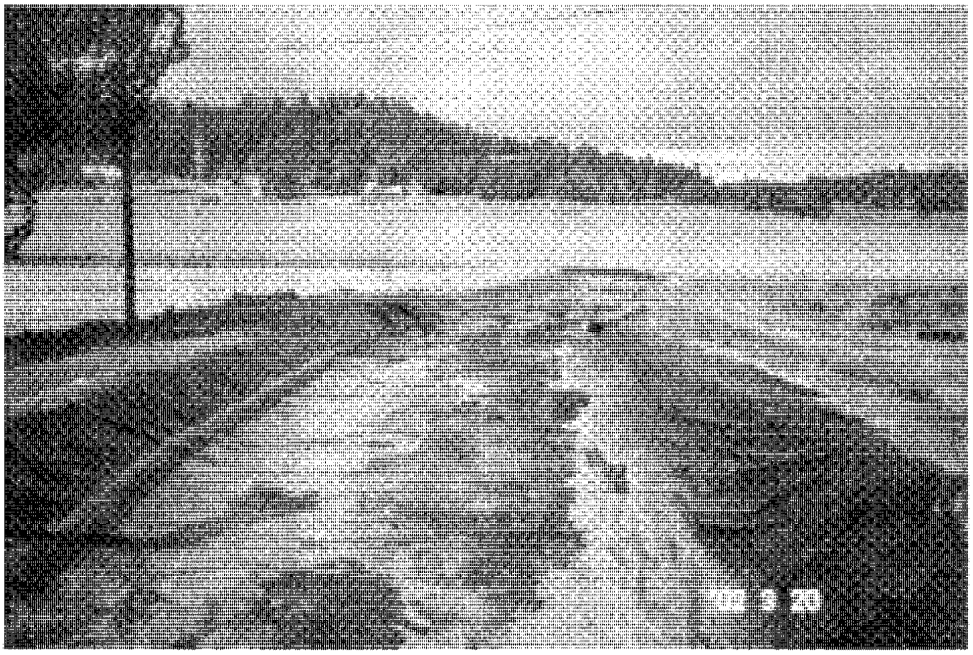


Photograph O-3.3.—View of north side of the canal showing the animal traffic that has occurred without damaging the geomembrane.

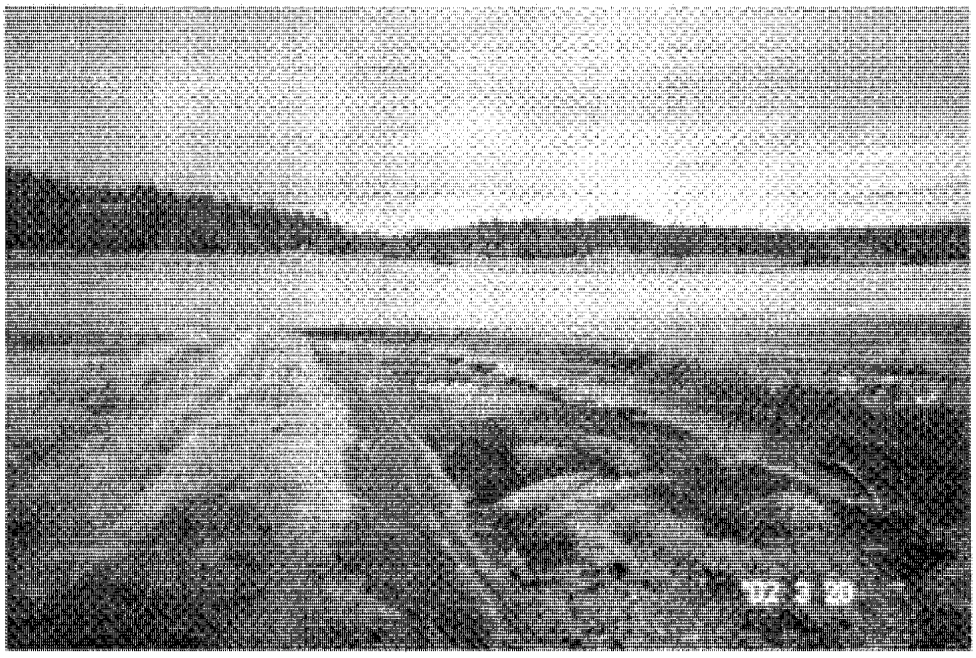
Test Section O-4—

Material:	Exposed 30-mil LLDPE geomembrane with geotextile cushion on side slopes only.
Description:	Layfield Plastics Enviro Liner is 30-mil LLDPE. The geotextile cushion on the side slopes is 8-oz needle-punched nonwoven (product number LP-8), supplied by Layfield Plastics.
Construction Cost:	\$0.78 per ft^2
Date installed:	November 1999 (2½ years old)
Location:	Ochoco Irrigation District (1,150 linear feet; 48,000 square feet)
Condition:	Excellent - The exposed LLDPE is in excellent condition after 2½ years of service. The factory and field seams are in excellent condition. Numerous animal tracks (mostly deer) are visible on the side slopes, and several hoofprints have left small dimples in the liner. A couple of these dimples have small tears (pinhole size up to 1/4 inch in diameter). The backhoe operator put 2 small tears (3 and 12 inches in diameter) in the LLDPE liner while removing the dike at the downstream end. The tears were halfway up the left bank. Both tears were patched with a hot-air welder. Sample - In November 2001, a 16- by 24-inch sample was taken for laboratory testing. The liner was patched with 30-mil LLDPE and a hot-air welder. Before patching, the LLDPE liner was cleaned with liquid detergent and a scrub brush. Although the 30-mil LLDPE is performing well after 2½ years of service, a 30-mil liner may prove too thin for long-term use as on exposed liner.
Maintenance:	Minimal maintenance required to date. Two backhoe tears were repaired at the downstream end of the test section. Animal hoof dimples and pinholes do not need to be repaired at this time. The District should monitor and repair any larger tears that develop.
Photographs:	1 through 6

Ochoco Irrigation District - Test Section O-4
Exposed 30-mil LLDPE Geomembrane with geotextile cushion on side slopes only

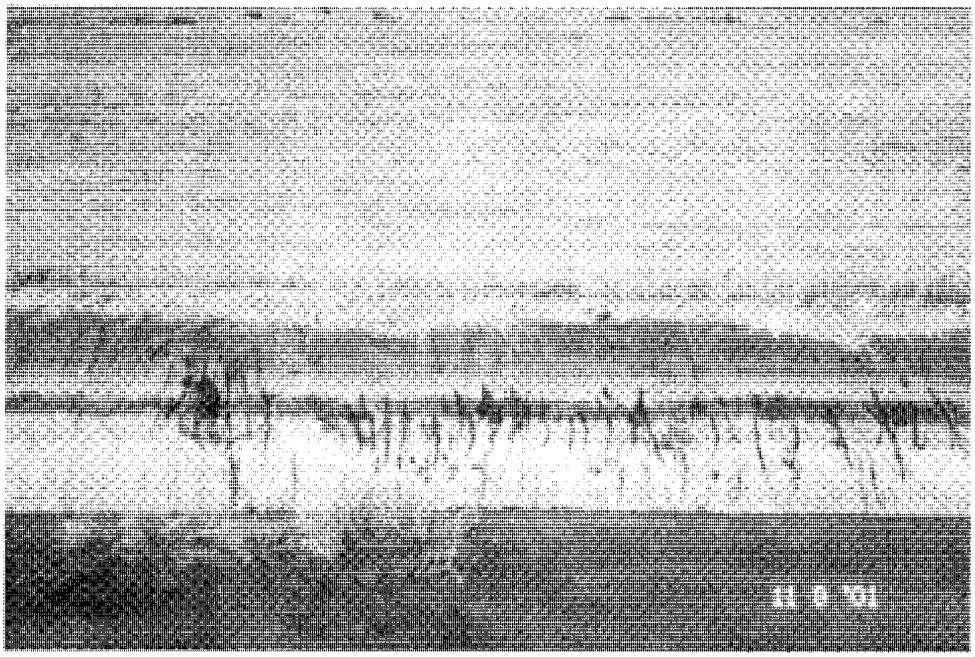


Photograph O-4.1.—Overview of the Ochoco Canal Test Section O-4, near the downstream area. It is in excellent condition.

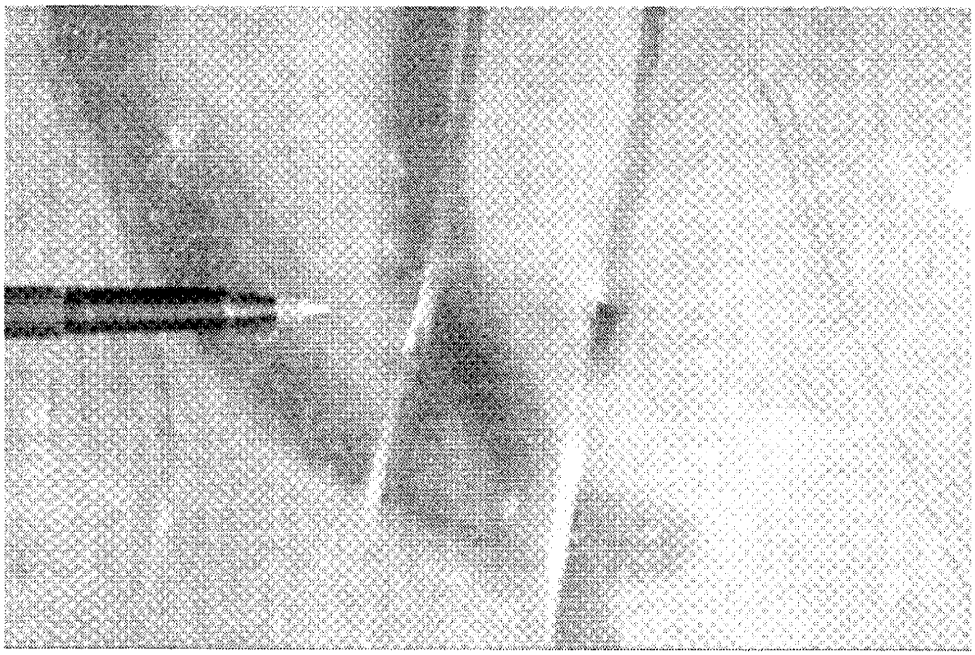


Photograph O-4.2.—Overview of the Ochoco Canal Test Section O-4, near the upstream area. It is in excellent condition.

Ochoco Irrigation District - Test Section O-4
Exposed 30-mil LLDPE Geomembrane with geotextile cushion on side slopes only



Photograph O-4.3.—View of the north side of the canal showing the animal traffic that has occurred without damaging the geomembrane.

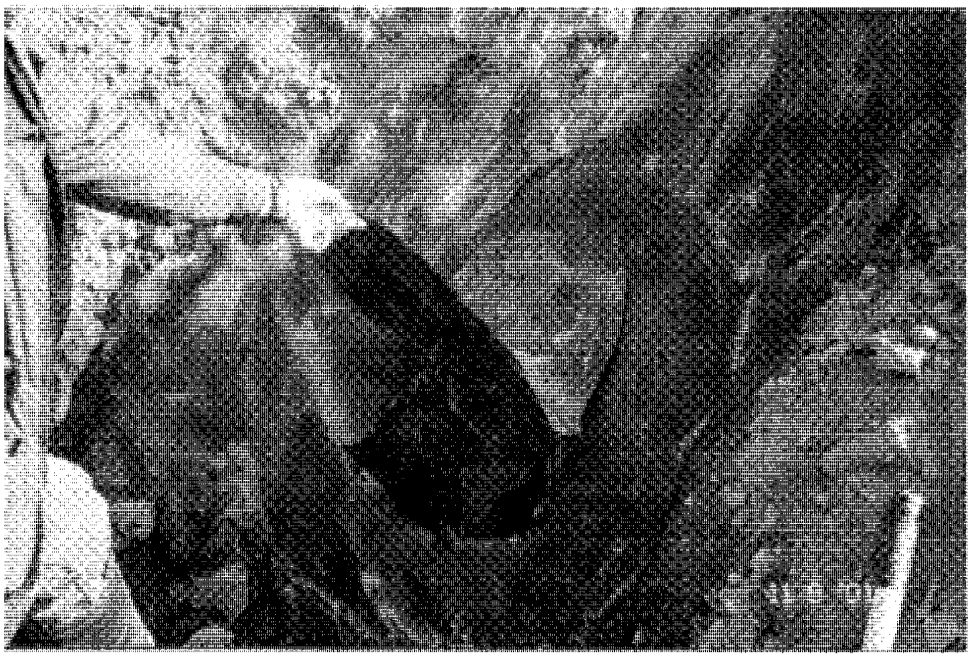


Photograph O-4.4.—Close-up view of pin size holes in the geomembrane that were caused by animals.

Ochoco Irrigation District - Test Section O-4
Exposed 30-mil LLDPE Geomembrane with geotextile cushion on side slopes only



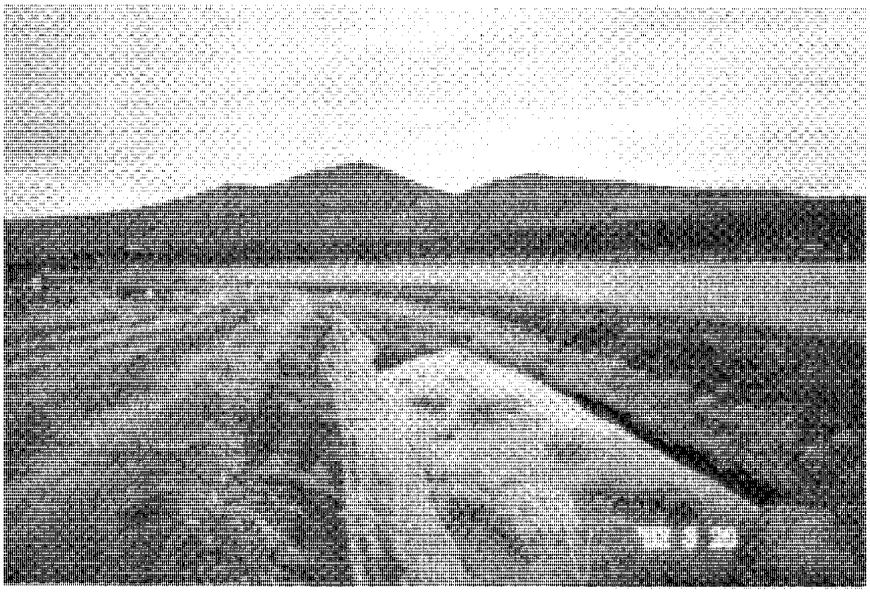
Photograph O-4.5.—View of patch made with an extrusion welder at the time of installation.



Photograph O-4.6.—View of patch being sized to cover hole. Damage occurred while removing the ponding test dike.

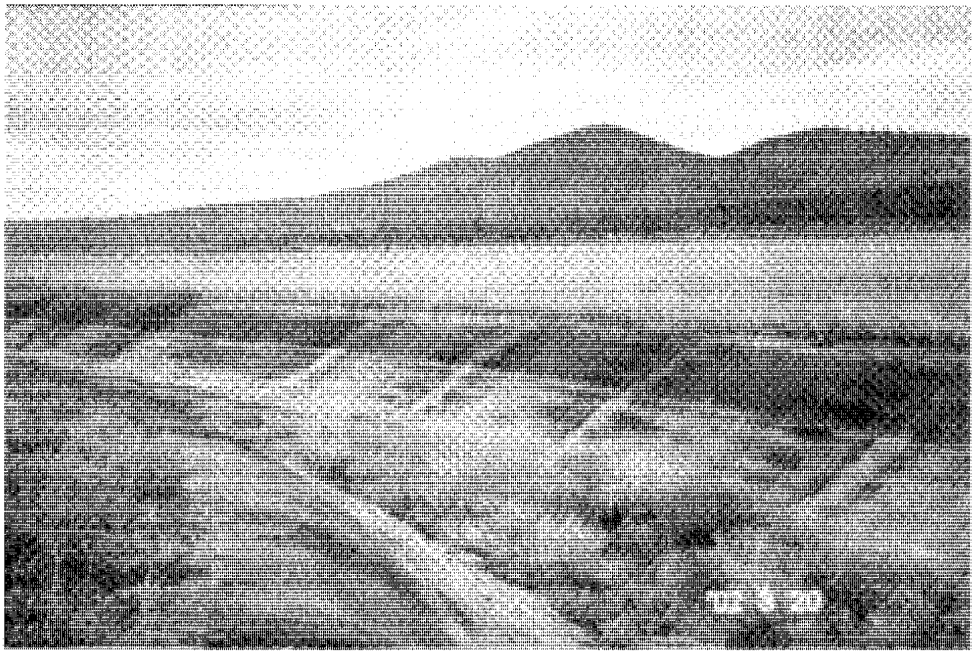
Test Section O-5—

Material:	Exposed 160-mil Coletanche NTP 2 ES
Description:	Coletanche NTP 2 ES (Coletanche) is an elastomeric bitumen geomembrane that combines Styrene-Butadiene-Styrene (SBS) polymer and asphalt with a polyester reinforcement. COLAS manufactures five grades of Coletanche. Only the Coletanche ES is polymer modified. Coletanche is provided in 160-mil thickness and roll widths of 4 and 5 meters (13 and 16.5 feet).
Construction Cost:	$1.51 per ft^2
Date installed:	November 2000 (1½ years old)
Location:	Ochoco Irrigation District (700 linear feet; 28,000 square feet)
Condition:	Excellent - The exposed Bituminous liner is in excellent condition after 1½ years of service. The numerous field seams (every 5 meters) are well bonded up to the anchor trench. Most of the sand surfacing has worn away. No alligator cracking is visible on the surface of the liner on the southern side slope. A very small amount of alligator cracking is visible on the liner surface on the northern side slope.
Maintenance:	None required at this time.
Photographs:	1 through 5



Photograph O-5.1.—Overview of the Ochoco Canal Test Section O-5, which is in excellent condition.

Ochoco Irrigation District - Test Section O-5
Exposed 160-mil Coletanche NTP 2 ES

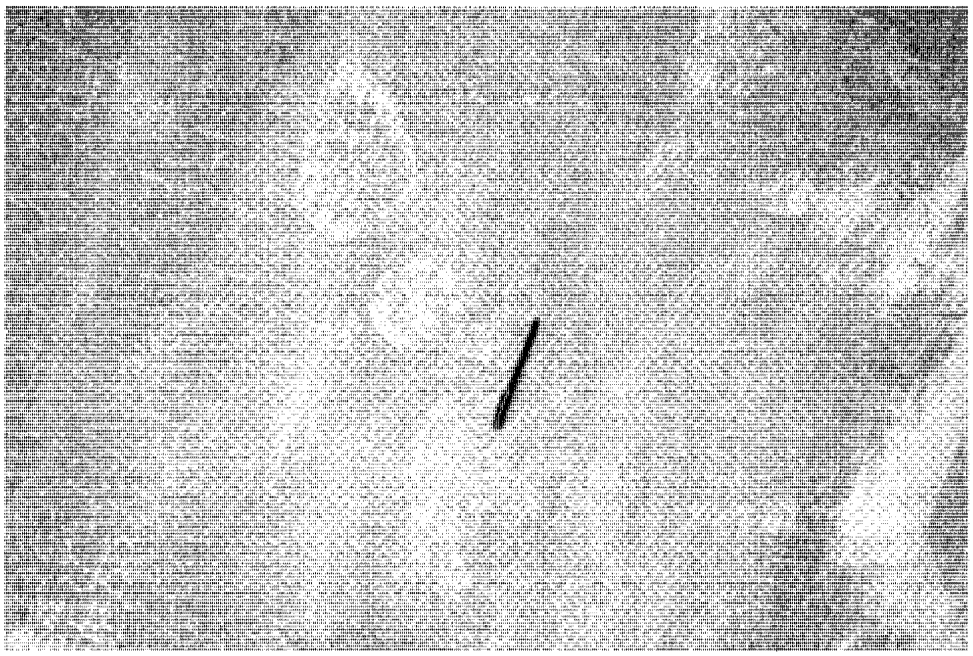


Photograph O-5.2.—View of the canal section looking downstream. Tumble weeds are gathered in the invert.

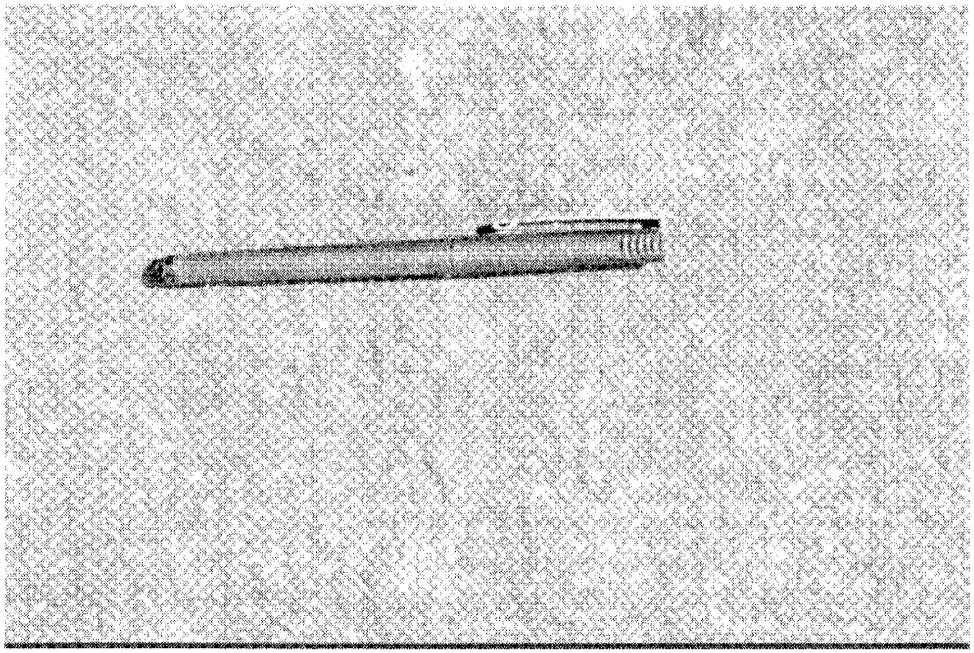


Photograph O-5.3.—View of north side of the canal showing the animal traffic that has occurred without damaging the geomembrane.

Ochoco Irrigation District - Test Section O-5
Exposed 160-mil Coletanche NTP 2 ES



Photograph O-5.4.—Alligator cracking that occurs with this type of lining material. This is only a surface pattern and does not penetrate the membrane.



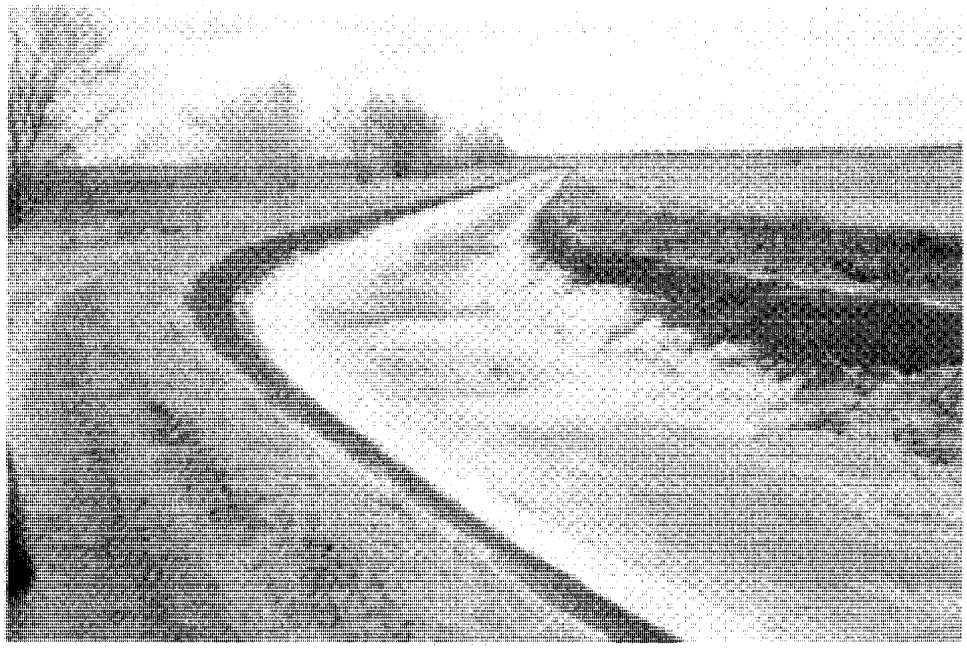
Photograph O-5.5.—View of the south side bank. Because the sun does not shine directly on the membrane, alligator cracking has not begun.

Lugert-Altus Irrigation District

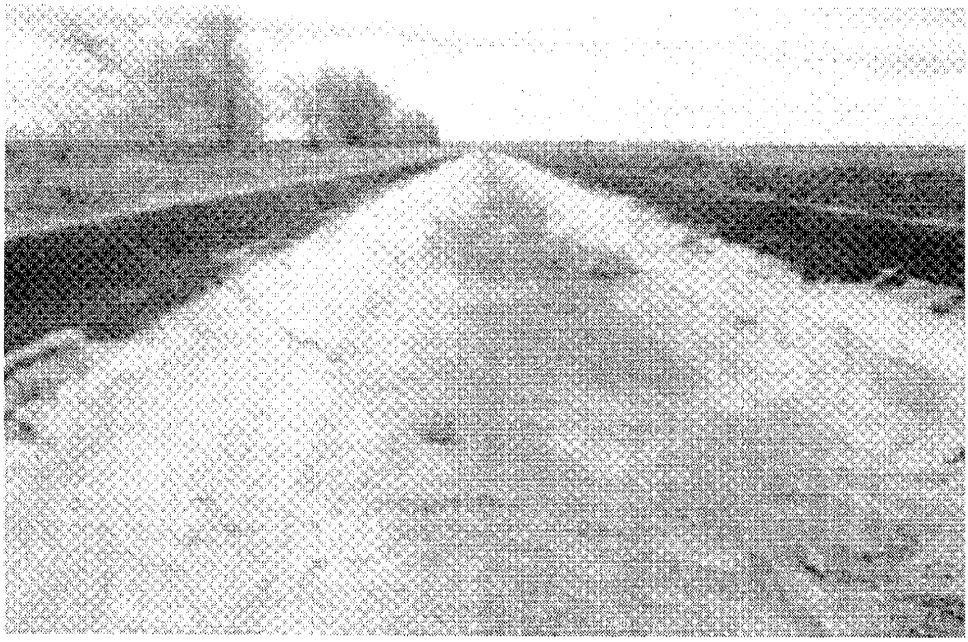
Test Section LA-1—

Material:	Exposed Teranap geomembrane
Description:	Teranap is an elastomeric bitumen geomembrane that combines 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:	160-mil exposed Teranap = \$1.37 per ft^2 120-mil exposed Teranap = \$1.19 per ft^2
Date installed:	May 1994 (8 years old)
Location:	West Canal - Lugert-Altus Irrigation District (2,400 linear feet; 70,000 square feet)
Condition:	Excellent - After 8 years of service, 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/day). Little to no sediment has collected in this test section. Deer entering the canal may have caused minor damage (one small hole on the side slope). In September 1996, a large storm deposited 4½ inches of rain in about 1 hour. Surface run-off 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 washed-out 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:	Minimal maintenance required to date. Performed: Irrigation District repaired the Teranap after the washout. Needed: Repair small hole on the side slope.
Photographs:	1 through 4

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

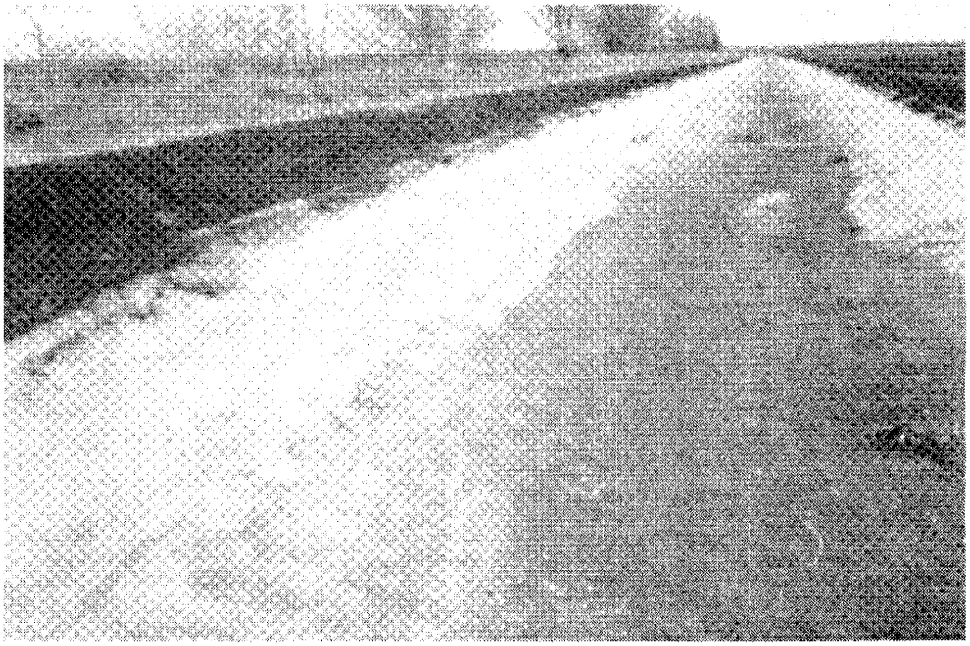


Photograph LA-1.1.—Canal Overview - After 8 years of service the material is in excellent condition.

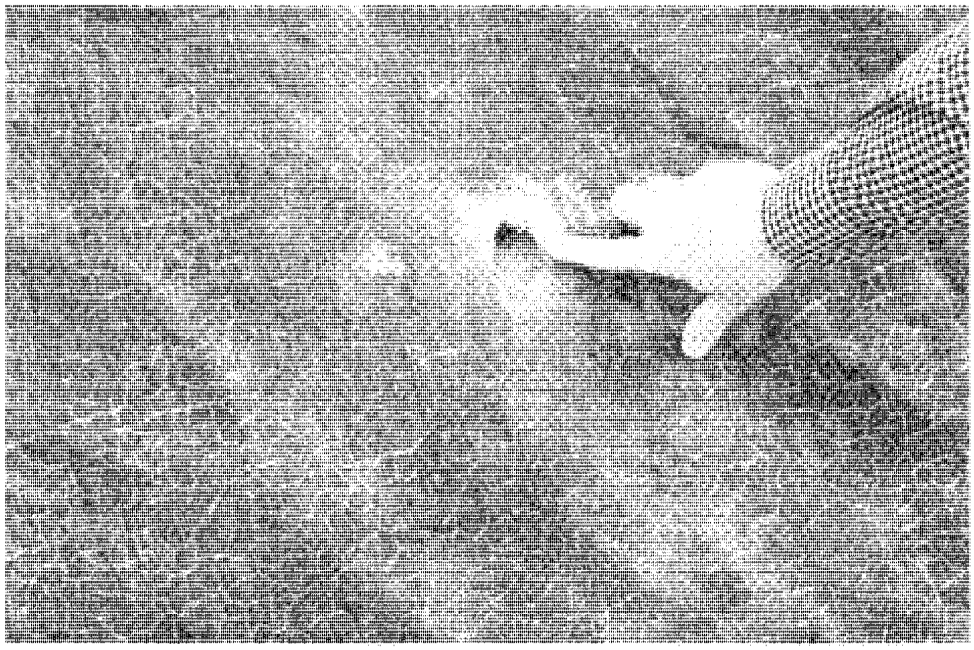


Photograph LA-1.2.—The Teranap shows very little wear and is in excellent condition.

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



Photograph LA-1.3.—ATV tracks can be seen in the bottom and on the side slopes. These vehicles do not appear to have damaged the material.



Photograph LA-1.4.—Teranap shows some surface cracking (alligator cracking) that is normal for this product. Also damaged by possibly a deer can be seen.

Juniper Flat Improvement Company

Test Section J-1—

Material:	Exposed 160-mil Teranap geomembrane
Description:	Teranap is an elastomeric bitumen geomembrane that combines Styrene-Butadiene-Styrene (SBS) polymer and asphalt with a polyester reinforcement.
Construction Cost:	$ 1.53 per ft^2
Date installed:	October 1997 (4½ years old)
Location:	Juniper Flat Improvement Company (District) (975 linear feet; 26,000 square feet)
Condition:	Excellent - After 4½ years of service, the Teranap shows only slight surface alligator cracking, and is still quite flexible. The subgrade is quite rough and contains many sharp rocks and roots. Little no sediment has collected in the invert. Most seams are well bonded. A couple of unbonded seams (6 to 12 inches long) were found and repaired with a propane torch. Numerous cows have walked through the canal and left hoof prints and scuff marks on the liner. In two locations, the cow's dew claws punctured the liner. Both these punctures have been repaired. Most of the test section is in excellent condition, except for a short section immediately downstream from the Walters Turnout. At this location, the geomembrane is in poor condition and is torn and ripped in numerous places. The district has experienced this same problem at another turnout where they installed this same bituminous liner. At both these turnouts, the liner was installed without a downstream cut off trench or concrete cap. Apparently, the lack of a downstream cutoff or the turbulence through the turnout or both are damaging the liner. This installation deficiency is not indicative of the overall performance. Sample - In November 2001, a 16- by 24-inch sample was taken for laboratory testing. The liner was patched with a bituminous liner patch and a propane torch. Before patching, loose dirt was removed with a wire brush.
Maintenance:	Minimal maintenance required to date. The District has resealed several seams with a propane torch. The District will continue to monitor the test section and repair the liner.
Photographs:	1 through 10

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

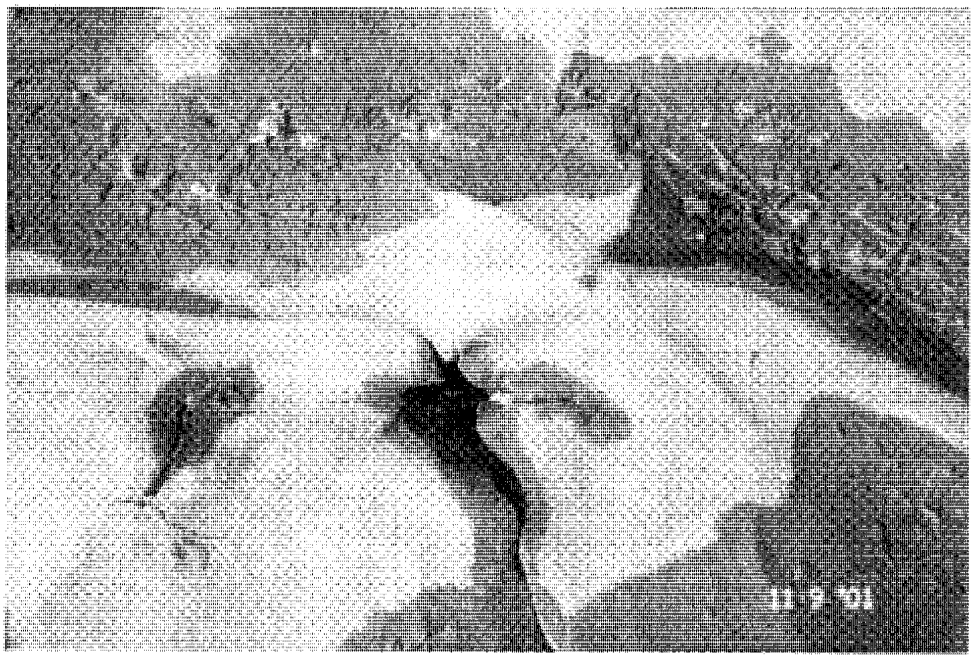


Photograph J-1.1.—Overview of the Juniper Flat Canal Test Section J-1 Walters Turnout. This is a view of the upstream area, which is in excellent condition.

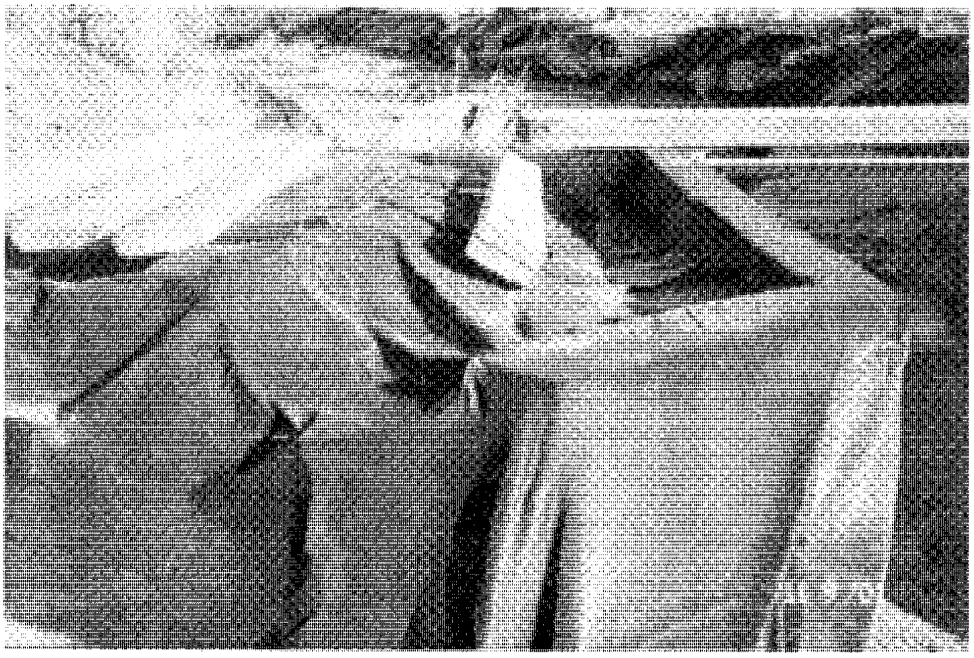


Photograph J-1.2.—Overview of the Juniper Flat Canal Test Section J-1 Walters Turnout. This is a view of the downstream area, which is has been destroyed by high water velocities and turbulence created by the turnout structure.

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



Photograph J-1.3.—Close up view of a star pattern hole in the lining in the downstream area.

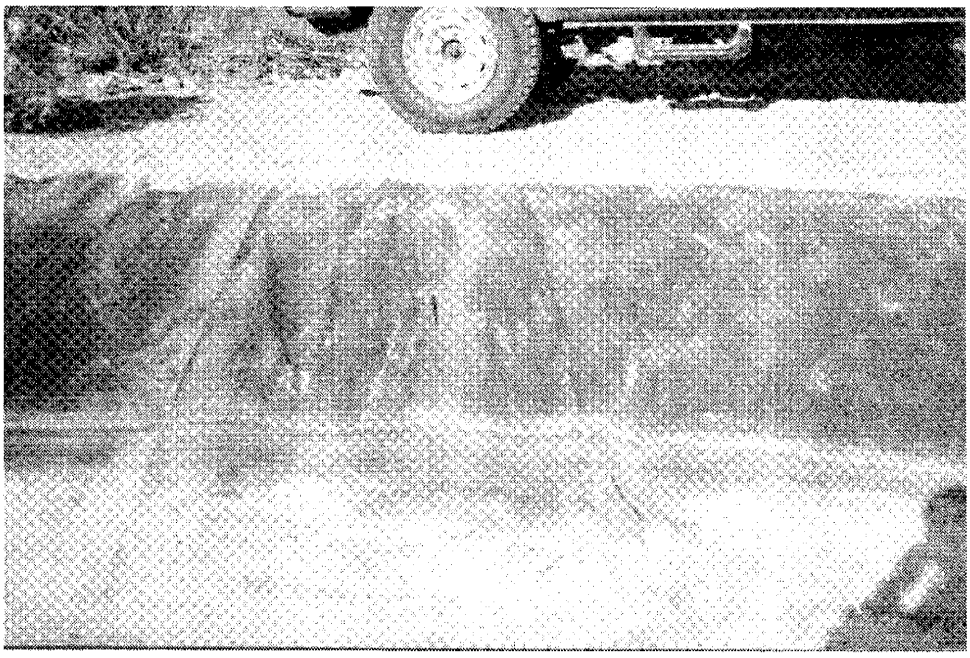


Photograph J-1.4.—View of the Walters Turnout, which was encased with the lining material, demonstrating how flexible this type of membrane can be.

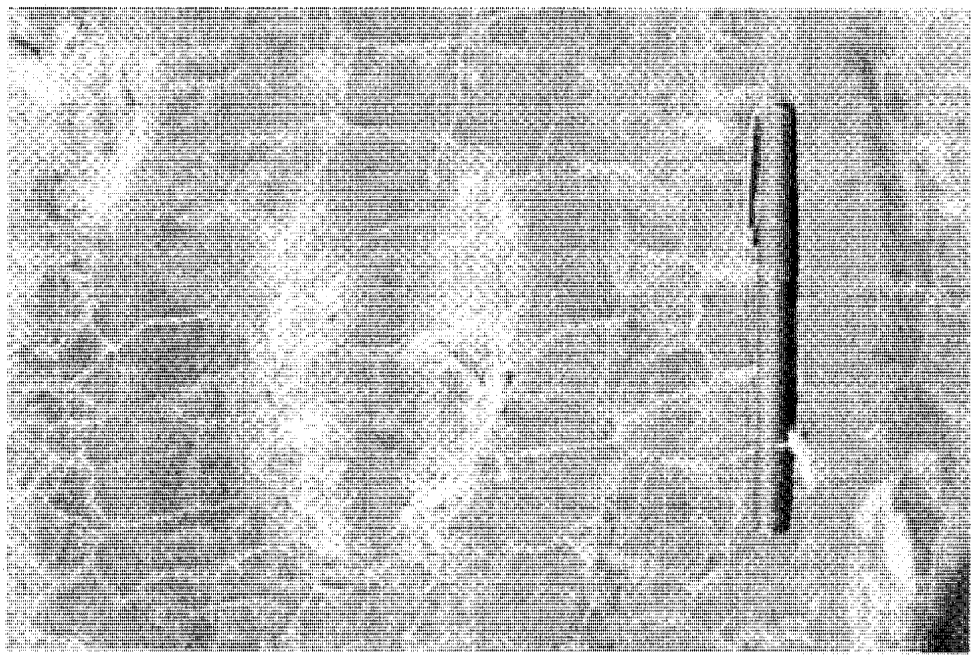
Juniper Flat Irrigation District - Test Section J-1
Exposed 160-mil Teranap Geomembrane



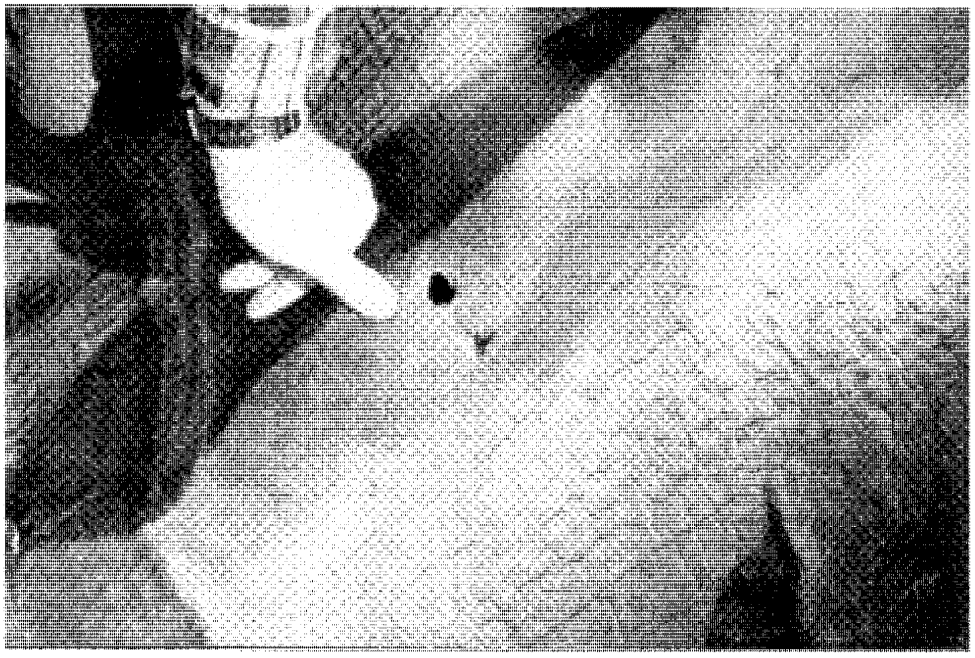
Photograph J-1.5.—Overview of the Juniper Flat Canal Test Section J-1, downstream from the Walters Turnout this section is in excellent condition.



Photograph J-1.6.—View of the north side of the canal showing the animal traffic that has occurred without damaging to the geomembrane.



Photograph J-1.7.—Closeup view of one of the hoof prints where the animal slid down the hot membrane and left a slide mark.



Photograph J-1.8.—Closeup view of a dewclaw puncture from a cow left in the membrane. The hole is about 1 inch in diameter.



Photograph J-1.9.—View of a patch being placed over a hole left by a coupon sample that Reclamation removed for testing.



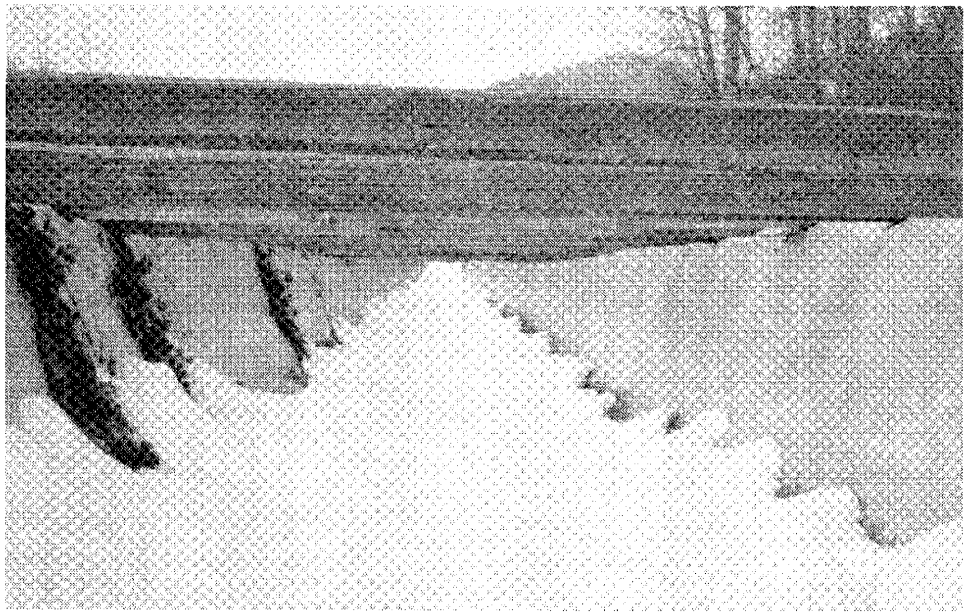
Photograph J-1.10.—View of a patch being place over a seam that was beginning to separate.

Frenchtown Irrigation District

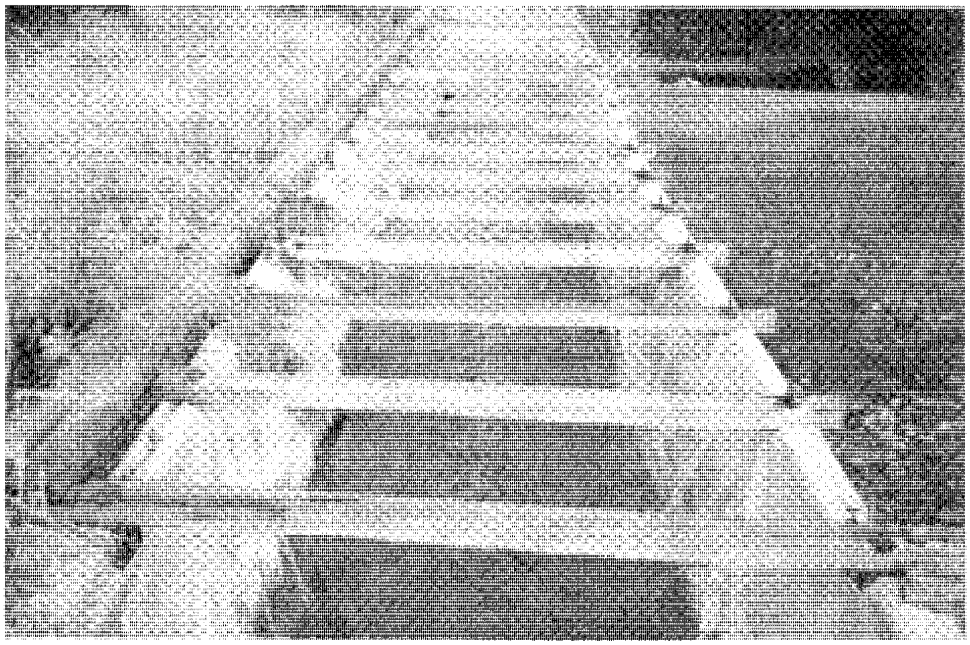
Test Section F-1—

Material:	Exposed 45-mil PP over an existing steel flume
Description:	The steel flume consists of a wooden frame with 3-foot sections of sheet metal. The flume is 320 feet long with a 12-foot perimeter. The liner is 45-mil reinforced polypropylene formulated for exposed applications. The reinforcement is a 10 x 10 polyester scrim.
Construction Cost:	\$0.90 per ft^2
Date installed:	April 1999 (3 years old)
Location:	Frenchtown Irrigation District - Mill Creek Flume (320 linear feet; 3,640 square feet)
Condition:	Excellent - The exposed PP is in excellent condition after 3 years of service. The factory seams are in excellent condition. The liner appears to be stretched a little tight in some areas, but is still performing well. No seepage is visible from this elevated flume.
Maintenance:	Minimal maintenance required to date. Performed: none Needed: Some shrubs growing up between the membrane and wooden tresses need to be removed to prevent damage to the membrane.
Photographs:	1 through 4

Frenchtown Irrigation District - Test Section F-1
Exposed 45-mil Reinforced Polypropylene over an Existing Steel Flume

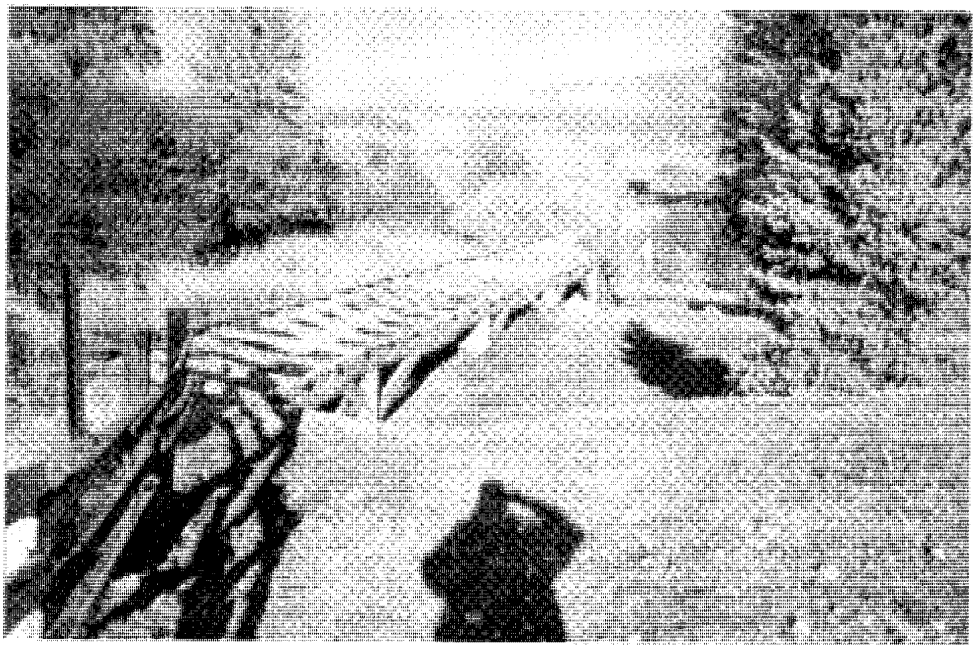


Photograph F-1.1.—Overview of the Frenchtown Flume Test Section F-1, which is in excellent condition.

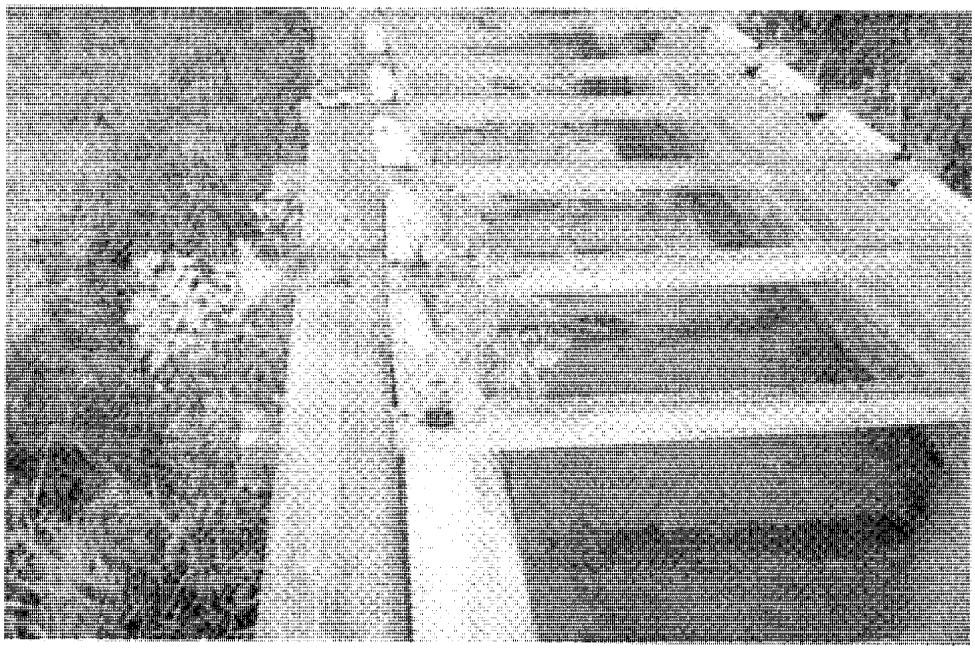


Photograph F-1.2.—View of bushes growing between the flume and the liner.

Frenchtown Irrigation District - Test Section F-1
Exposed 45-mil Reinforced Polypropylene over an Existing Steel Flume



Photograph F-1.3.—View of area of seepage under the flume, this area has remained dry following geomembrane installation.



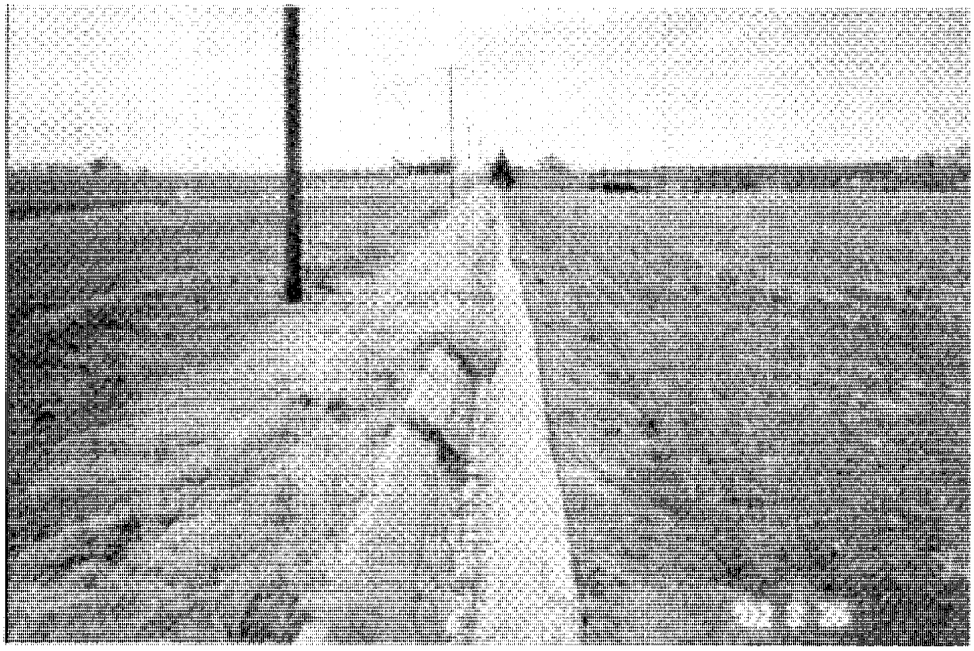
Photograph F-1.4.—Closeup view of the weeds and bushes growing between the flume and liner.

Twin Falls—Rick Stone Ranch, Farm Lateral

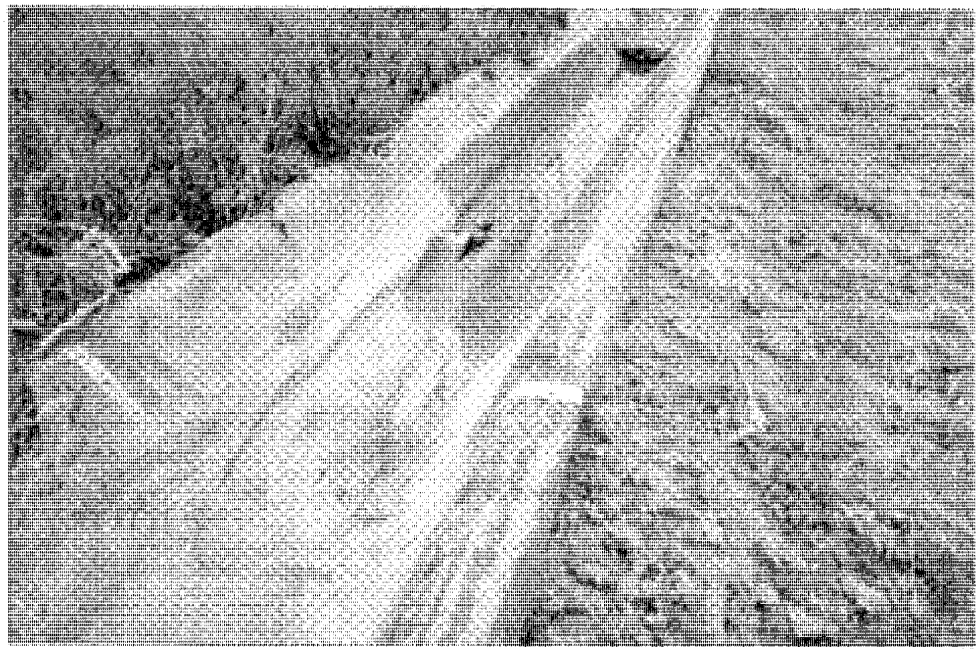
Test Section TF-1—

Material:	Exposed 40-mil wet-applied polyurethane geocomposite over existing concrete
Description:	The liner consists of two layers of 3-oz heat-bonded, non-woven geotextile saturated with liquid polyurethane resin. The total minimum thickness is 40 mils. The geotextile is Typar 3301 non-woven spunbonded polypropylene geotextile.
Construction Cost:	$1.43 per ft^2
Date installed:	June 2000 (2 years old.)
Location:	Twin Falls, Idaho - about 7 miles west of town near Filer, Idaho (1,920 linear feet, 11,500 square feet)
Condition:	Very Good - The polyurethane geocomposite is still intact, well bonded to the existing concrete base, and still flexible. During the first irrigation season, water got under a low section of the liner, creating a dam at the first downstream steel cut-off band. The owner cut an 18-inch slit in the membrane to release the trapped water. The slit will be repaired during the winter. Burrowing animals and wind have exposed some of the liner on the west side of the north-south section. The material is still attached to the concrete but needs to be backfilled again.
Maintenance:	Minimal maintenance required to date. The slot needs to be patched and the membrane needs to be reburied in the anchor trench. In 2001, a beer truck ran off the road and damaged a portion of this test section (photo 8). Repairs were performed using a bituminous liner, because the farmer can only perform very small repairs with the polyurethane patch material. Costs for this special repair were not included in estimated maintenance costs.
Photographs:	1 through 8

Twin Falls - Rick Stone Ranch, Farm Laterial Test Section TF-1
Exposed 40-mil Wet-applied Polyurethane Geocomposite over Existing Concrete

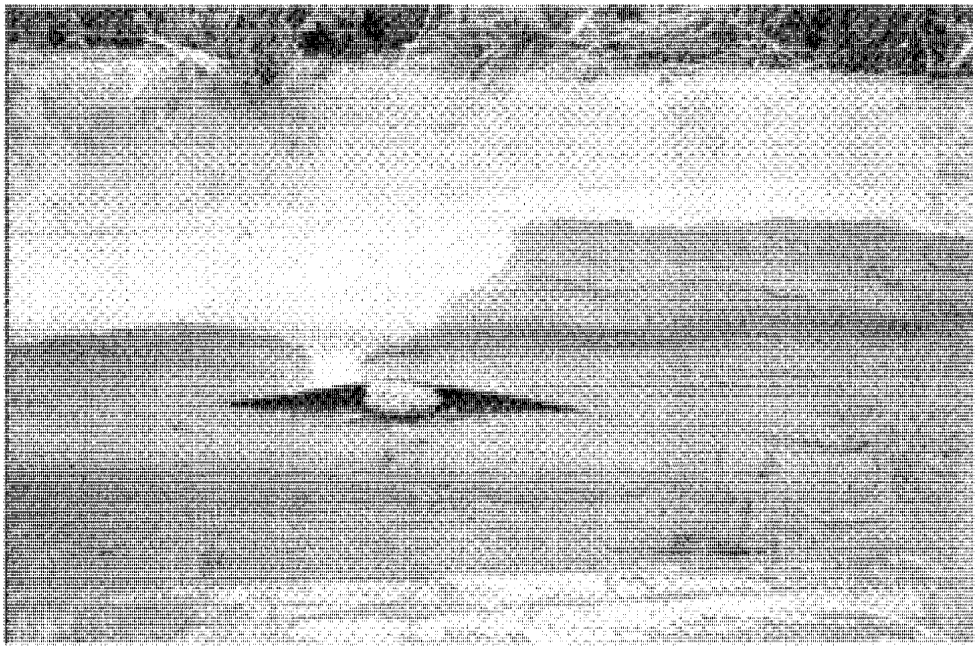


Photograph TF-1.1.—Overview of the Twin Falls Farm Lateral Test Section TF-1 (East/West portion), which is in excellent condition.



Photograph TF-1.2.—View of a cut made in the liner by the rancher. Water got under the liner at a low area, upstream, and was trapped at the steel band. The cut was to let the water out from under the liner.

Twin Falls - Rick Stone Ranch, Farm Laterial Test Section TF-1
Exposed 40-mil Wet-applied Polyurethane Geocomposite over Existing Concrete

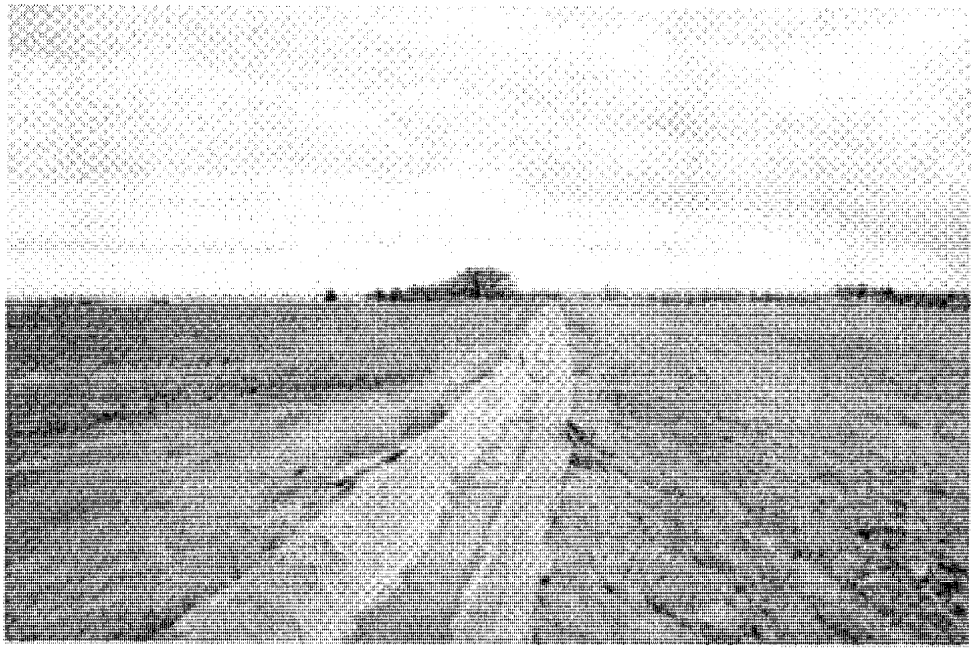


Photograph TF-1.3.—View of cut made by the rancher. Cut is about 18 inches long and will be repaired by the rancher with some of the mix left with him by the contractor.

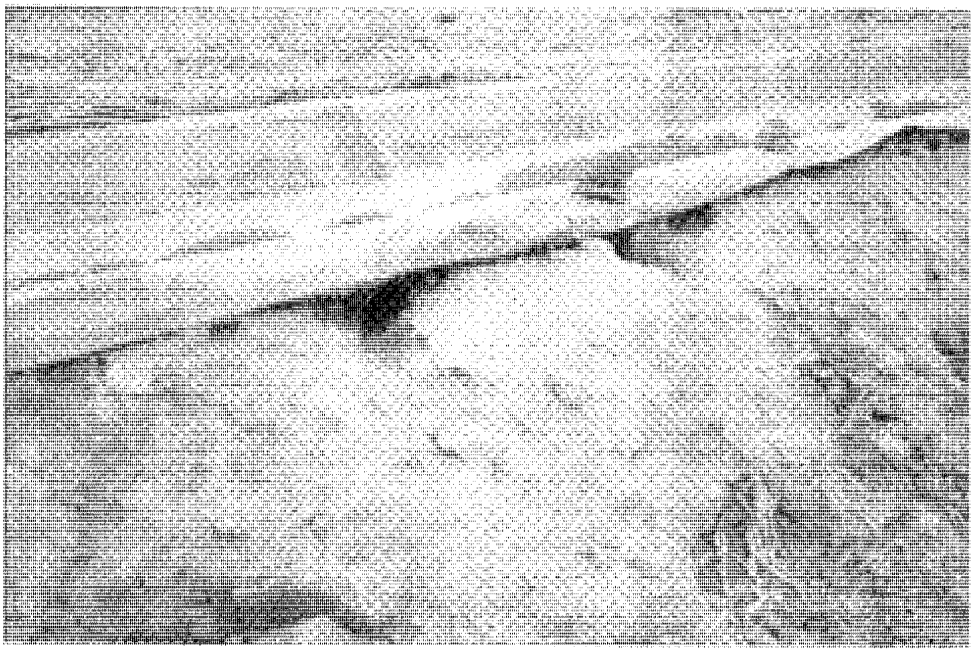


Photograph TF-1.4.—Closeup view of some of the scale and dried mud left by the water.

Twin Falls - Rick Stone Ranch, Farm Lateral Test Section TF-1
Exposed 40-mil Wet-applied Polyurethane Geocomposite over Existing Concrete

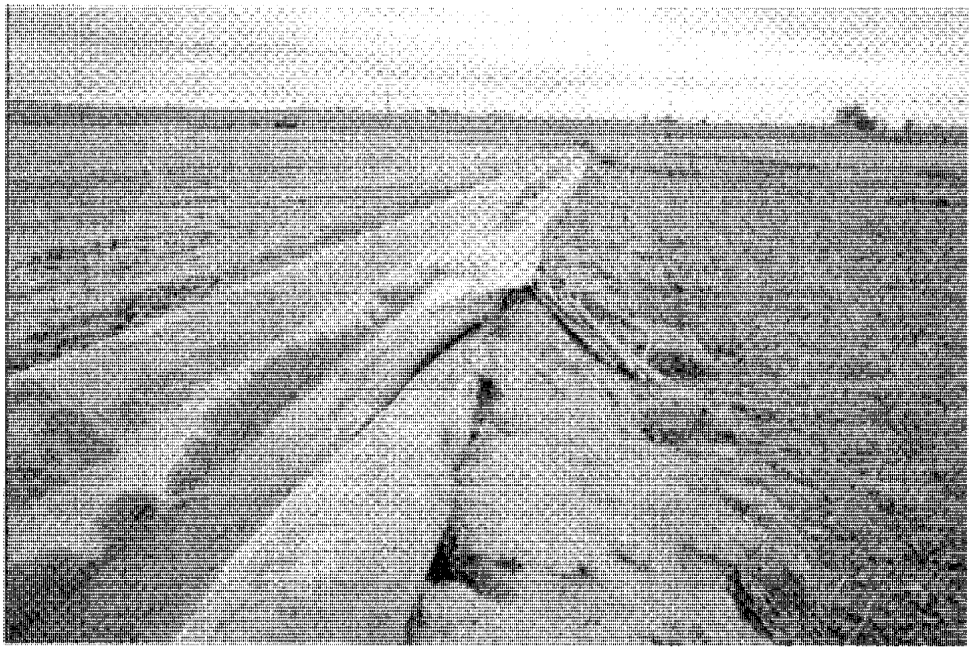


Photograph TF-1.5.—Overview of the Twin Falls Farm Lateral Test Section TF-1 (north-south portion), which is in excellent condition.

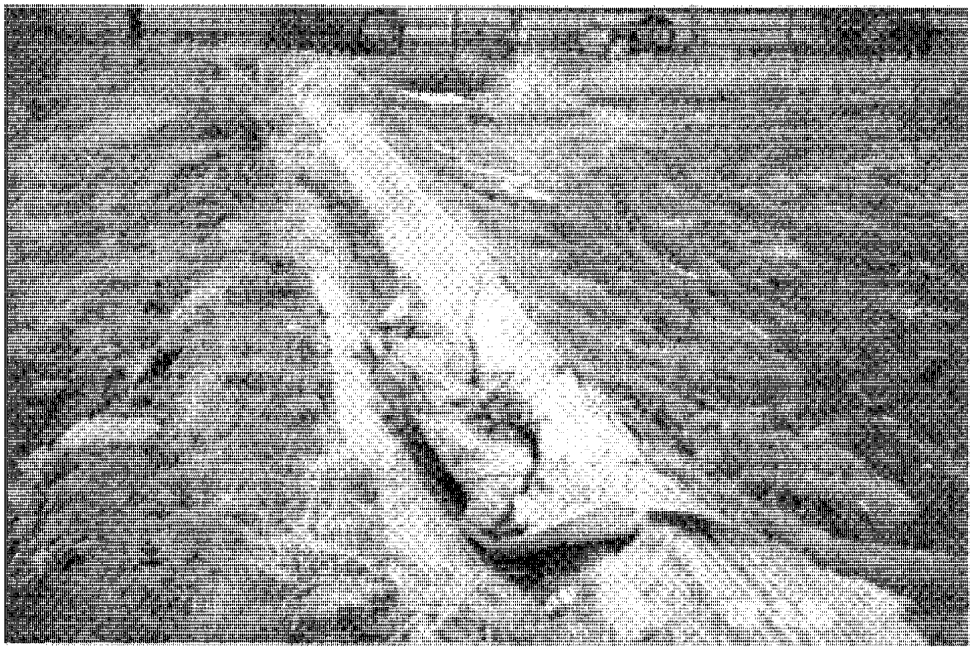


Photograph TF-1.6.—View of the sides of the ditch, where rodents have burrowed at the anchor trench.

Twin Falls - Rick Stone Ranch, Farm Lateral Test Section TF-1
Exposed 40-mil Wet-applied Polyurethane Geocomposite over Existing Concrete



Photograph TF-1.7.—View of an area where the wind has caught the sides and torn the liner loose at a seam.



Photograph TF-1.8.—Section damaged by a beer truck that went off the road and hit the concrete ditch. Repairs have been made with a bituminous liner.

Lewiston Orchards Irrigation District

Test Section LO-1—

Material:	Exposed 45-mil reinforced Metallocene
Description:	The 45-mil geomembrane consists of 2 layers of Metallocene that has been reinforced with a 10 by 10 polyester scrim. The geomembrane is tan on the top and black on the bottom. Metallocene is reportedly a copolymer blend of HDPE and polypropylene. Metallocene is manufactured by Serrot who was acquired by GSE Lining Technology. This material may not be available.
Construction Cost:	\$0.99 per ft^2
Date installed:	June 2000 (2 years old.)
Location:	Lewiston Orchards Irrigation District, Lewiston Idaho - Sweetwater Main Canal (1,920 linear feet, 11,500 square feet)
Condition:	Excellent - The reinforced Metallocene is in excellent condition after 2 years of service. The District raised the free board in couple of areas by pulling the liner out of the anchor trench and pushing dirt behind the membrane.
Maintenance:	Minimal maintenance required to date.
Photographs:	1 through 4

Lewiston Orchards Irrigation District - Test Section LO-1
Exposed 45-mil Reinforced Metallocene

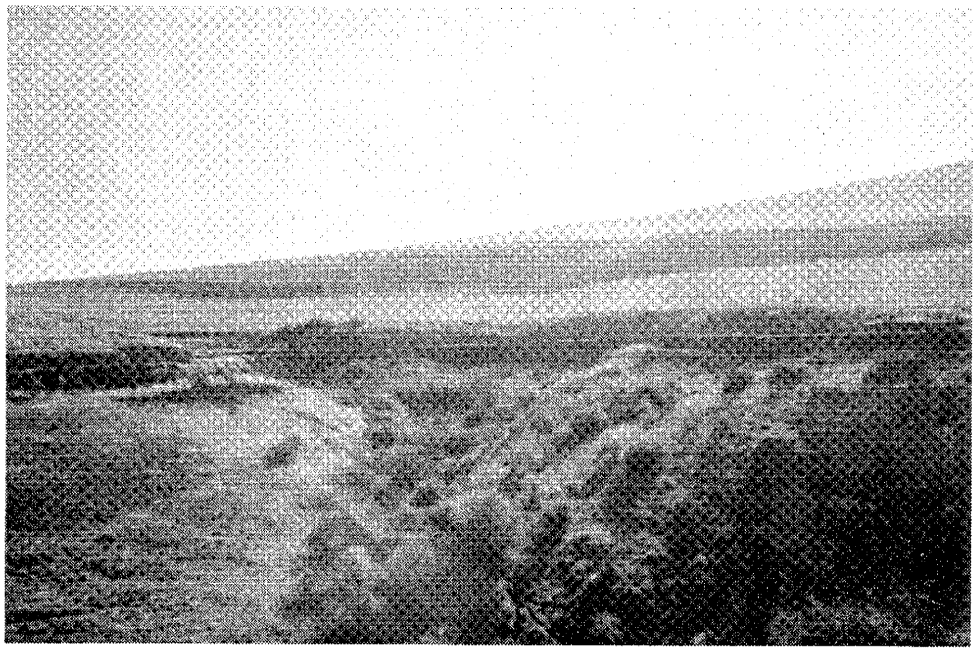


Photograph LO-1.1.—Overview of the Lewiston Orchards Canal Test Section LO-1, which is in excellent condition.

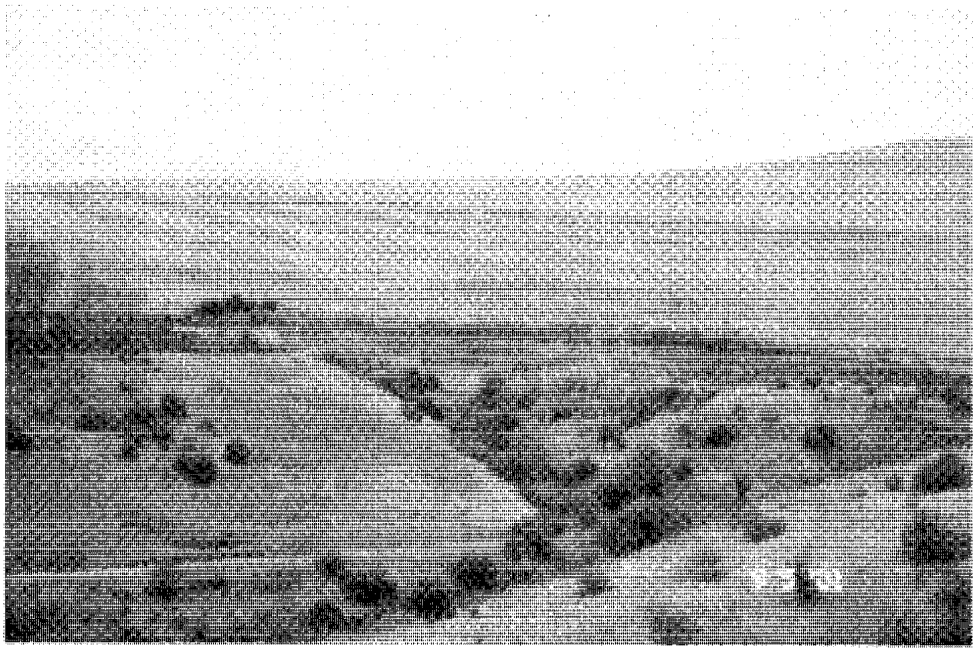


Photograph LO-1.2.—View of the canal downstream, where the canal did not have enough free board and the water was over the edge. The since District has fixed this area.

Lewiston Orchards Irrigation District - Test Section LO-1
Exposed 45-mil Reinforced Metallocene



Photograph LO-1.3.—View before installation of lining in this area. Note the amount of vegetation in the draws.



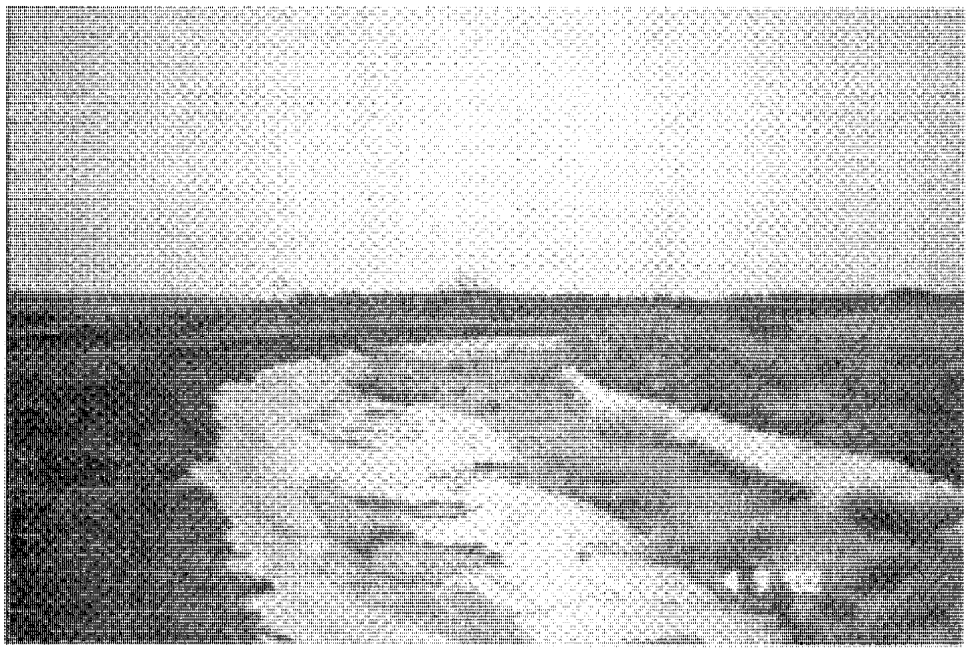
Photograph LO-1.4.—View after installation of lining in this area. Note the amount of vegetation in the draws.

Buffalo Rapids Irrigation District

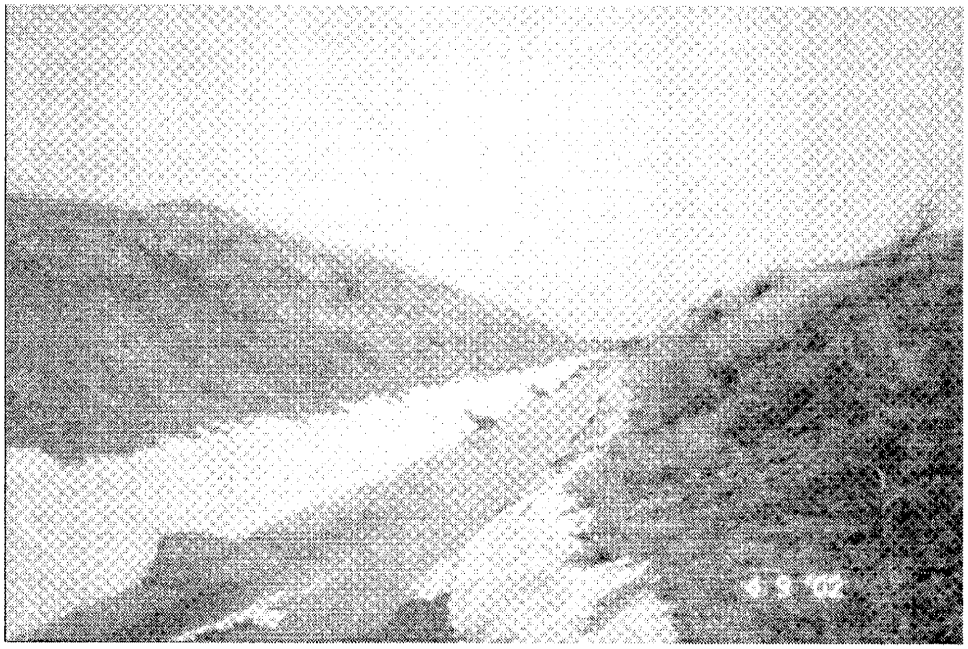
Test Section BU-1a and 1b—

Material:	Exposed 60-mil textured HDPE white with a 10-oz geotextile cushion Exposed 60-mil textured HDPE white
Description:	The 60-mil textured HDPE geomembrane is coextruded with a white surface on one side and a black surface on the other. The geomembrane is installed with the white side up. Geotextile is a 10-oz needle-punched nonwoven (Synthetic Industries 1071).
Construction Cost:	\$1.26 per ft^2 for BU-1a \$1.12 per ft^2 for BU-1b
Date installed:	April 2001 (1 year old.)
Location:	Buffalo Rapids Irrigation District, Glendive, Montana (4,900 linear feet, 189,500 sq feet of geomembrane, 57,400 sq feet of geotextile)
Condition:	Excellent after 1 year of service. The only damage is from heavy rainstorms that washed away some of the embankment, exposing some of the geomembrane on the anchor berm.
Maintenance:	Minimal maintenance required to date. Backfill on anchor berms needs to be replaced.
Photographs:	1 through 4

Buffalo Rapids Irrigation District - Test Section BR-1a and BR-1b
Exposed 60-mil Textrued HDPE White with 10-oz geotextile

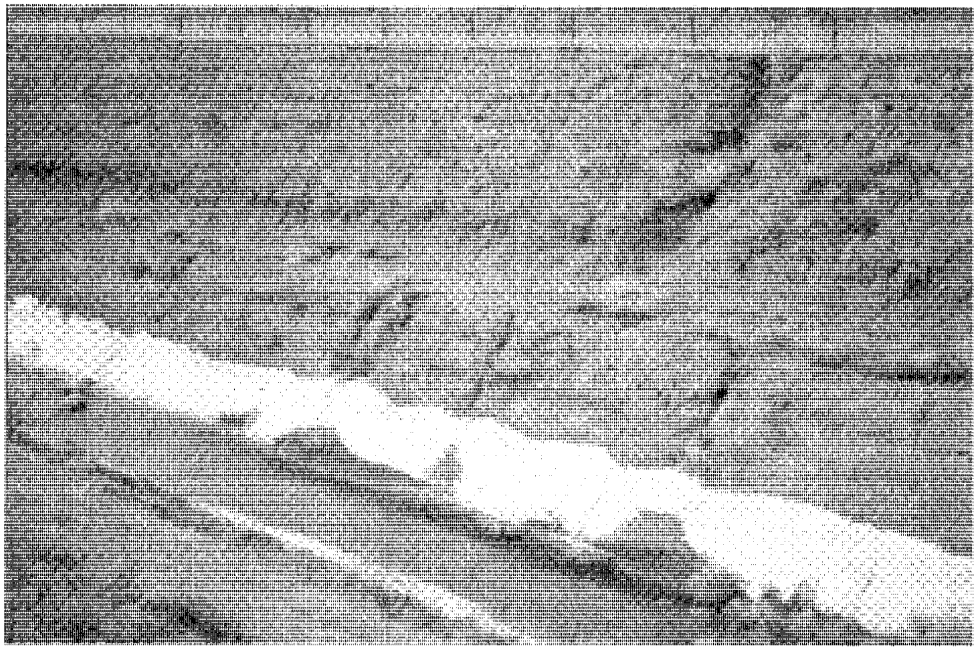


Photograph BU-1.1.—Overview of the Buffalo Rapids Canal Test Sections BU-1a and BU-1b, which are in excellent condition.

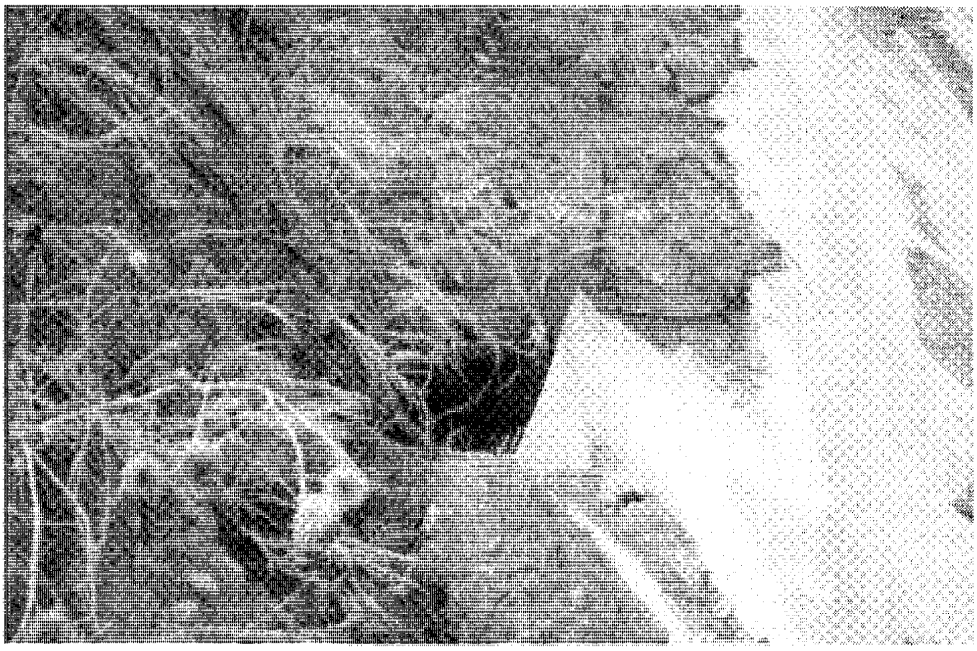


Photograph BU-1.2.—Overview of the canal looking downstream through the big cut area. The lining is in excellent condition.

Buffalo Rapids Irrigation District - Test Section BR-1a and BR-1b
Exposed 60-mil Textrued HDPE White with 10-oz geotextile



Photograph BU-1.3.—During the spring runoff some areas above the lining had eroded.



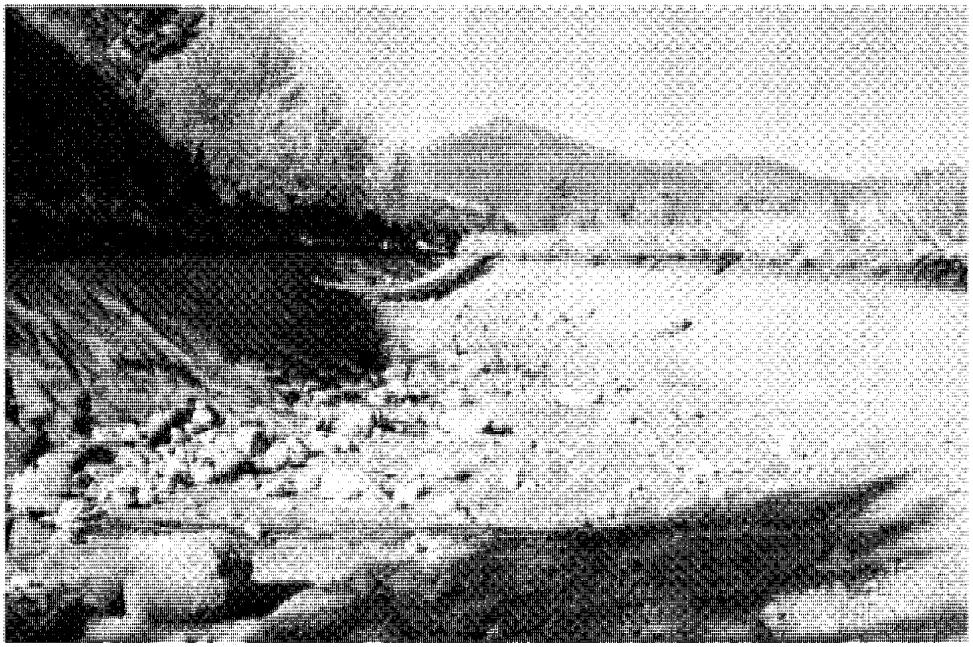
Photograph BU-1.4.—View where the lining was exposed in the anchor trench. These areas will be reburied by the district.

Bitter Root Irrigation District

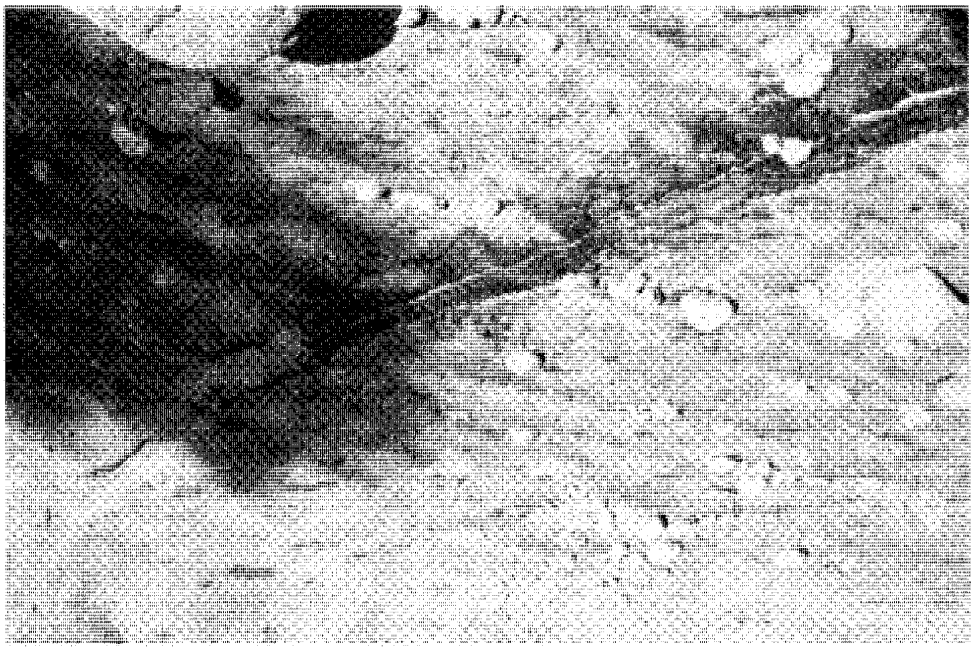
Test Section BI-1—

Material:	Exposed 20-mil Geocomposite
Description:	The membrane is GeoComp 8-20-8 EVA geocomposite. It is composed of a gray 8-oz geotextile cushion; 20-mil EVA; and a black, 8-oz, geotextile cover. Both polyester geotextiles and EVA geomembrane are made from recycled polymer. The geomembrane composite is installed with the black geotextile facing up for UV protection. Material data sheets are included in appendix A.
Construction Cost:	20 mil EVA Canal [3] = $0.83 per ft^2
Date installed:	October 2001 (1 year old.)
Location:	Bitter Root Irrigation District. Near Hamilton MT (900 linear feet, 4,500 square feet)
Condition:	Excellent after 1 year of service. The only damage is two seams which came apart. Material has captured some sediment in the exposed textile helping to protect it.
Maintenance:	Need to fix two seams.
Photographs:	1 and 2.

Bitter Root Irrigation District - Test Section BI-1
Exposed 20-mil Geocomposite



Photograph BI-1.1.—Over all view of the Bitter Root main canal. The lining is in excellent condition. Note the large rocks which rolled off the bank on onto the material no damage was done to the liner.



Photograph BI-1.2.—View of one of the seams in the invert. All seams are holding up very well. Two small separations were found which have been repaired.

Coupon Testing

Test coupons were taken from six of the exposed geomembrane test sections for laboratory evaluation (table 13). Each test coupon measured approximately 3 square feet (2- by 1½-ft). The test coupons were centered on the waterline, so that half the coupon was above the waterline and half was below. Each test coupon was tested for physical properties and compared to the manufacturer's published values and to original samples that were retained at the time of test section construction (See appendix D for complete results). The materials and test results are summarized below.

Table 13.—Coupon Testing of Exposed Geomembrane test sections

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

Discussion - Although many of the exposed geomembranes visually appear to be in excellent condition, the changes in physical properties suggest that many are beginning to degrade. As expected, the physical degradation is usually less severe below the waterline.

80-mil HDPE - Yield strength and yield elongation are unchanged. Breaking strength is down slightly, and elongation at break is down significantly (especially above the waterline). Chemical Analysis (appendix D) show Melt Index (molecular weight) is unchanged; however, OIT is down significantly, indicating that the antioxidants are being used up. Based on these results, service life is predicted at 20 to 25 years.

30-mil PVC - This material has stiffened significantly (increased tensile, increased modulus, decreased elongation). Aged material now exhibits a clear yield point. Based on these results, this material is near the end of its useful service life (10-15 years).

45-mil Hypalon - Tear strength is down significantly (especially above the waterline). Hypalon is very difficult to patch (repair) because of surface oxidation. If numerous tears in the test section are not repaired, this material is near the end of its useful service life (10-15 years).

36-mil Hypalon - Tear strength is down significantly (both above and below the waterline). Hypalon is very difficult to patch (repair) because of surface oxidation. If numerous tears in this test section are not repaired, this material is near the end of its useful service life (10-15 years).

45-mil EPDM - Elongation and tear strength are down significantly. Based on these results, service life is predicted at 15-20 years.

30-mil LLDPE - Tensile and tear are down slightly. Because the liner thickness is only 30 mils, service life is predicted at only 10-15 years.

CHAPTER 4
SEEPAGE ANALYSIS

The primary purpose of all the canal lining alternatives is to conserve water by reducing seepage. Full-scale ponding tests are performed preconstruction and postconstruction to determine the effectiveness of each test section. Most of the ponding tests have been performed on the Arnold and North Unit Test Sections, and the results are summarized in tables 14, 15, 16, and 17.

Preconstruction Ponding Tests

Arnold

The preconstruction seepage rate for the Arnold test sections ranged from 0.64 foot/day to 1.4 feet/day, and averaged 1.0 feet/day. This value agrees with theoretical values based on the soil type and geology (Swihart and Haynes, 1994).

North Unit

The measured preconstruction seepage rate for the North Unit test sections ranges from 3 to 20 ft/day. These values are higher than expected and are not considered representative. For the following reasons, the average seepage rate for the North Unit test sections is believed also to be about 1.0 ft/day:

1. Inflow-outflow data from the 26-mile North Unit Main Canal shows an average seepage rate of about 1.1 feet/day and a conveyance loss of 20 to 30 percent.

2. Pond 1 was chosen as an area of known high seepage from visual observations of whirlpools during canal filling. Therefore, the measured seepage rate of 20 feet/day applies only to pond 1 and is not considered representative of the whole canal.

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

Ochoco

Preconstruction ponding tests preformed by Reclamation for this study show an average seepage rate of 0.91 foot/day.

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 years postconstruction), and 1998 (6 years postconstruction). Ponding tests were planned for 10 years after construction, but they were not performed because of scheduling conflicts. The results from all the ponding tests are summarized in table 14. 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 14, and some of the ponding tests were repeated in 1998 with earthen dikes.

North Unit Ponding Test

The original eight North Unit test sections (N-1 thru N-4, and N-6 thru N-9) were 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). Shotcrete was used on the 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), 2001 (3 years postconstruction - RCC Invert with shotcrete side slopes). The locations of the ponding tests is shown in figure 8.

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), 1998 (6-year post-construction), and 2001 (10-years postconstruction).

The results of the North Unit ponding tests are shown in tables 15 and 16.

Ochoco Ponding Tests

Postconstruction ponding tests were performed in 2001, when most test sections were about 2 years old. The results are summarized in table 17.

Table 14.—Arnold Canal Ponding Tests

Type of liner	Test section	Pre-construction 1991 (ft^3/ft^2-day)	Postconstruction 1 year 1993 (ft^3/ft^2-day)	Postconstruction 5 years 1997 (ft^3/ft^2-day)	Postconstruction 6 years 1998 (ft^3/ft^2-day)	Effectiveness estimated long-term (percent)
GM with Shotcrete cover	A - 1		0.05 *95%	0 - 0.3 70 - 100%		95%
	A - 2	1.40	0.11 89%			
Exposed GM	A - 3		-0- 100%	0 - 0.1 90 - 100%		90%
	A - 4		-0- 100%	0.1 - 0.2 80 - 90%	0.04	
	A - 5		0.01 99%	0 - 0.5	96%	
	A - 6		0.12 88%	50 - 100%		
GM with grout mattress cover	A - 7	0.64	0.10 90%	0 - 0.4 60 - 100%	0.05 95%	95%
Grout mattress	A - 8		0.02 98%	0.3 - 0.5 50 - 70%	0.29 71%	70%
	A - 9		0.07 93%			
	A - 10		0.07 93%			

* Effectiveness based on percent reduction from average preconstruction seepage rate of 1.0 ft^3/ft^2-day.

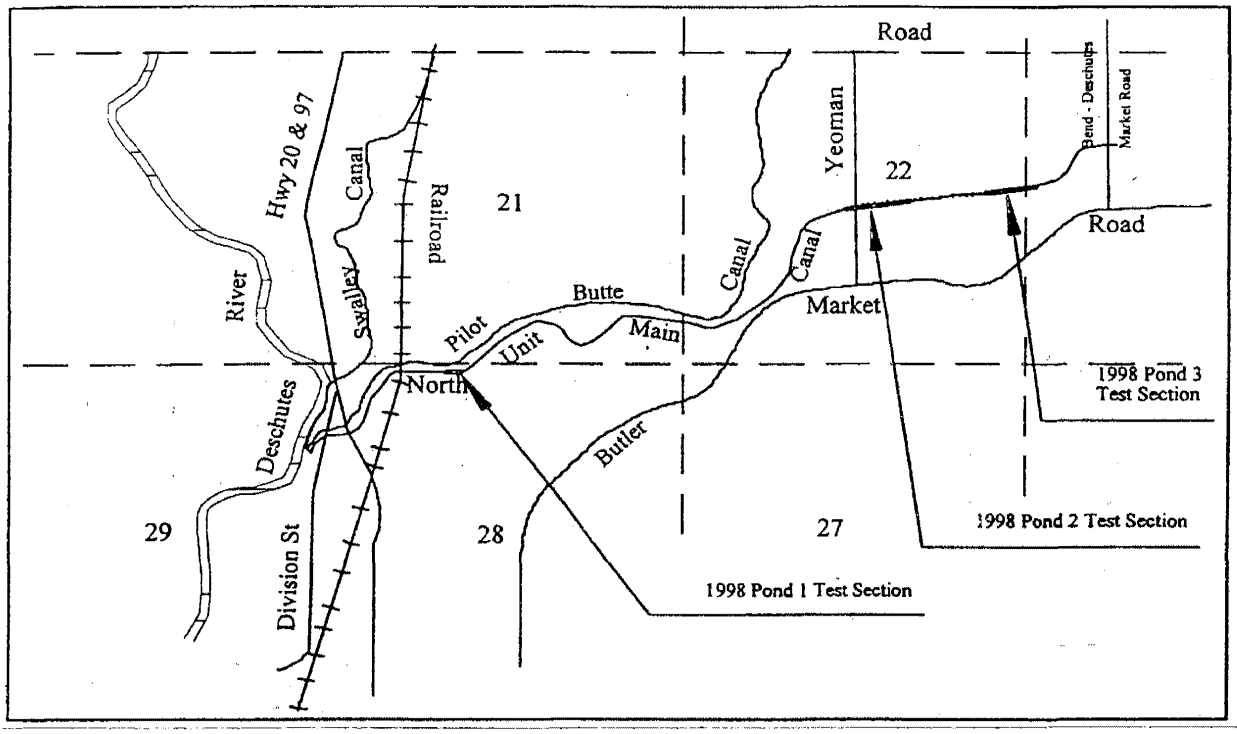


Figure 8.—General Location Map for North Unit Main Canal 1998 Ponding Tests.

Table 15.—North Unit Canal Ponding Tests

Type of liner	Test section	Pre-construction 1991 (ft^3/ft^2-day)	Pre-construction 1996 (ft^3/ft^2-day)	Post-construction 1994 (ft^3/ft^2-day)	Post-construction 1998 (ft^3/ft^2-day)	Post-construction 2001 (ft^3/ft^2-day)	Effectiveness estimated long-term (percent)
RCC invert with Shotcrete side-slope*	Pond No.1		20.45				70%
	N - 1	3.1 - 5.4	3.1 - 5.6			0.32 3yr 90%	
	N - 2						
	N - 3		2.3 - 3.8				
	N - 4						
	N - 5						
Shotcrete**	N - 6	1.1					
	N - 7			0.44 2yrs. 60%	0.40 6yrs. 64%	0.45 10yrs. 59%	
	N - 8						
	N - 9						

* Effectiveness of RCC with Shotcrete side slopes (N-1 through N-5) is based on a preconstruction seepage rate of 3.1 feet/day

** Effectiveness of Shotcrete (N6 through N9) is based on a preconstruction seepage rate of 1.1 feet/day, determined by inflow-outflow measurements. (See section on preconstruction ponding tests.)

Table 16.—North Unit Canal Ponding Tests - Invert only

Type of liner	Test section	Pre-construction 1991 (ft^3/ft^2-day)	Pre-construction 1996 (ft^3/ft^2-day)	Post-construction 1998 (ft^3/ft^2-day)	Effectiveness estimated long-term (percent)
	Pond No. 1		20.45	3.18 1 yr 84%	
					40%
RCC	N - 1		3.1 - 5.6		
	N - 2			2.53	
invert	N - 3	3.1 - 5.4	2.3 - 3.8	1yr 18%	
	N - 4				
only	N - 5				

Table 17.—Ochoco Canal Ponding Tests

Type of Liner	Test Section	Pre Construction 2000 (ft^3/ft^2-day)	Post Construction 2 year 2001 (ft^3/ft^2-day)	Effectiveness Estimated long-term (percent)
LLDPE	O - 4		0.01 99%	90%
Bituminous	O - 5	0.91	0.01 99%	90%
Buried GCLs both types	O - 1a O - 3a		0.11 89%	90%
Exposed GCL type DN	O - 2a		0.08 92%	See foot note*
Exposed GCL type CL	O - 2b		0.03 97%	See foot note*
EPDM	O - 3a O - 3b		0.01 99%	90%

* The GCL manufacturer recommends GCL installation with 1 to 4 feet of earth cover. The exposed GCLs were installed as an experiment to determine durability under worst-case conditions. Although the exposed GCLs showed good seepage control, they were beginning to degrade rapidly from UV light. After 2 years, the exposed GCL tests were terminated and the GCLs were buried.

Effectiveness

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

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

Table 18.—Test section results

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

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

Exposed Geomembrane—Exposed geomembrane includes HDPE, Hypalon, Bituminous, EVA, PP, LLDPE, and PVC. Geomembranes are quite watertight when new, but continued effectiveness depends on resistance to both UV and mechanical damage. Effectiveness is estimated at 90 percent, based on the ponding tests. 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 30 years because of the potential for mechanical and UV damage. The design life also varies depending of the UV resistance of the polymer and thickness of the geomembrane. Exposed geomembranes will require more maintenance than concrete linings. ***If not properly maintained, long-term effectiveness and service life can be drastically reduced.***

Fluid-applied Geomembrane—Fluid-applied geomembrane is another type of exposed geomembrane. The geomembrane is fabricated onsite. Maintenance costs are the same as for an exposed geomembrane. However, the anticipated durability is lower (10 to 15 years) because of problems with field manufacturing control quality, thickness, and other physical properties. Adverse weather (wind, rain, cold) aggravates these problems. About half the test sections with fluid-applied membranes failed within the first 5 years of service.

Concrete with Geomembrane underliner—Concrete includes RCC, shotcrete, and grout-filled mattress. Geomembrane underliner can include any type of geomembrane. Our test sections used PE geocomposite, HDPE, VLDPE, and PVC. Geomembrane underliners are usually thinner than those for exposed applications. The concrete will crack and degrade, but the system will remain watertight because the geomembrane is the water barrier and the concrete acts only as a protective cover. Therefore, small cracks and defects in the concrete cover do not affect the system effectiveness. Ponding tests at Arnold show effectiveness of about 95 percent. Maintenance requirements are the same as for concrete alone ($0.005 per ft^2 per yr). Durability is also the same as for concrete alone (40 to 60 years).

CHAPTER 5
BENEFIT/COST ANALYSIS

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

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

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

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

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

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

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

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

Table 20.— Benefit/Cost Analysis

Test Section	Const Cost ($/ft2)	Durability Range* (years)	Annualized Const Cost ($/ft2-yr)	Maintenance Cost ($/ft2-yr)	Total Cost ($/ft2-yr)	Effectiveness Seepage Reduction (%)	Benefit/Cost
A-1	2.43	40-60	0.049	0.005	0.054	95	3.7
A-2	2.52	40-60	0.050	0.005	0.055	95	3.6
A-3	1.38	20-30	0.055	0.010	0.065	90	2.9
A-4	1.05	10-15	0.084	0.010	0.094	90	2.0
A-5	1.11	10-15	0.089	0.010	0.099	90	1.9
A-6	1.03	10-15	0.082	0.010	0.092	90	2.0
A-7	2.54	40-60	0.051	0.005	0.056	95	3.5
A-8	1.92	40-60	0.038	0.005	0.043	70	2.9
A-9 & A-10**	1.79						
N-1	4.33	5-15	0.433	0.010	0.443	40	0.2
N-2	3.92	5-15	0.392	0.010	0.402	40	0.2
N-3	2.64	1-5	0.880	0.010	0.890	90	0.2
N-4	2.64	1-5	0.880	0.010	0.890	90	0.2
N-5 Invert	1.74	40-60	0.035	0.005	0.040	40	2.1
N-5	2.00	40-60	0.040	0.005	0.045	70	3.2
N-6	2.20	40-60	0.044	0.005	0.049	70	3.0
N-7	2.14	40-60	0.043	0.005	0.048	70	3.0
N-8	2.14	40-60	0.043	0.005	0.048	70	3.0
N-9	2.07	40-60	0.041	0.005	0.046	70	3.2
T-1	1.70	5-15	0.170	0.010	0.180	40	0.5
T-2	2.16	10-15	0.173	0.010	0.183	90	1.0
T-3	1.40	10-15	0.112	0.010	0.122	90	1.5

* An average of the durability range was used for the B/C analysis

** Removed at District's request - No analysis

Table 20.—Benefit/Cost Analysis - continued

Test Section	Const Cost ($/ft2)	Durability Range* (years)	Annualized Const Cost ($/ft2-yr)	Maintenance Cost ($/ft2-yr)	Total Cost ($/ft2-yr)	Effectiveness Seepage Reduction (%)	Benefit / Cost
O-1a Buried	0.82	20-40	0.027	0.005	0.032	95	6.1
O-1b Buried	0.87	20-40	0.029	0.005	0.034	95	5.8
O-2a Exposed**	0.76						
O-2b Exposed**	0.81						
O-3a	0.84	15-20	0.048	0.010	0.058	90	3.2
O-3b	0.87	15-20	0.050	0.010	0.060	90	3.1
O-4	0.78	10-15	0.062	0.010	0.072	90	2.6
O-5	1.51	20-30	0.060	0.010	0.070	90	2.7
LA-1	1.37	20-30	0.055	0.010	0.065	90	2.9
	1.19	20-30	0.048	0.010	0.058	90	3.2
J-1	1.53	20-30	0.061	0.010	0.071	90	2.6
F-1	0.90	15-20	0.051	0.010	0.061	90	3.0
TF-1	1.43	10-15	0.114	0.010	0.124	90	1.5
LO-1	0.99	15-20	0.057	0.010	0.067	90	2.8
BU-1a	1.26	20-25	0.056	0.010	0.066	90	2.8
BU-1b	1.12		0.050	0.010	0.060	90	3.1
BI-1	0.83	15-20	0.047	0.010	0.057	90	3.3
Underliner	0.54	40-60	0.011	0.000	0.011	25	4.7
Maintenance							
Concrete + GM	0	—	—	0.005	0.005	47.5	19.6
Concrete	0	—	—	0.005	0.005	35	14.5
Exp GM	0	—	—	0.010	0.010	45	9.3
Liquid Applied	0	—	—	0.010	0.010	45	9.3

* An average of the durability range was used for the B/C analysis

** Buried after 2 years - No analysis

cover, and concrete alone. Each of these alternatives has advantages and disadvantages, and is discussed in further detail below. In addition, the B/C ratios of a couple of options are discussed, including installation of the geomembrane underliner component and performing annual maintenance.

Exposed Geomembrane—HDPE (A-3), Hypalon (A-5 and A-6), and Teranap (L-1 and J-1) are types of exposed geomembranes. 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. Exposed geomembranes show promise for some special applications such as lining of existing steel flumes (test section F-1). 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).

Concrete alone—RCC with shotcrete side slopes (N-5), shotcrete alone (N-6, N-7, N-8 and N-9), and grout-filled mattress (A-8) are examples of how concrete can be used alone. 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 cracks over time, and the long-term effectiveness is only about 70 percent.

Geomembrane with Concrete Cover—A variety of geomembranes and concrete covers, including shotcrete over PE (A-1), shotcrete over PVC (A-2), and grout-filled mattress over PVC (A-7), are found in their group. 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 and the concrete protects the geomembrane from mechanical damage and weathering. Maintenance requirements are virtually identical to concrete alone.

Geomembrane Lining of Steel Flumes—Liquid Boot (T-3) and PP (F-1) are in this group. 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. Liquid Boot is the only spray-applied membrane that is still in service. Steel flumes may be a specialty niche for this type of product. Surface preparation by sandblasting of the steel flume (T-2) has not proven cost effective because the expensive sandblasting did not improve performance over brooming (T-3).

Spray-applied Geomembranes—This group includes sprayed-in-place foam (N-1 and N-2), coated geotextile (N-3 and N-4), 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 above.

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.

Buried GCL—This study suggests that buried GCL's have very favorable benefit-cost ratios of about 6; however, these results are very preliminary as the GCL's have only been in service about 2 years. Also,

the GCL is the only buried geomembrane included in this study and the reported costs might not be directly comparable to exposed geomembranes and geomembranes with concrete cover. Specifically, costs associated with over-excavation and flatter side-slopes have not been included for the buried GCL test sections.

Maintenance—During the 10-year study period, the maintenance requirements of all the alternatives have been quite low ($0.005 to $0.010 per ft^2/year). However, this small amount of annual maintenance has a large effect on durability and effectiveness. This study suggests that annual maintenance can double the service life of all the alternatives. B/C analysis shows that every dollar spent on maintenance can return $10 to $20 in conserved water. The benefits of annual maintenance cannot be overstressed!

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 and inversely proportional to construction costs. Therefore, changes in any of these parameters would cause proportional changes in all the alternatives but would not change any of their relative positions. Maintenance costs have been low for all the alternatives and therefore have minimal effect.

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 1.9 to 3.7 (table 21).

Table 21.—Benefit/Cost ratios of four types of canal linings

Type of Lining	Durability (years)	Maintenance ($/ft^2/yr)	Effectiveness (percent seepage reduction)	B/C
Fluid-applied Membrane	10 - 15 yrs	$0.010	90 %	0.2 - 1.5
Concrete alone	40 - 60 yrs	$0.005	70 %	3.0 - 3.5
Exposed Geomembrane	10 - 25 yrs	$0.010	90 %	1.9 - 3.2
Geomembrane with Concrete Cover	40 - 60 yrs	$0.005	95 %	3.5 - 3.7

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

   a. Concrete—Concrete has excellent durability but only 70 percent long-term effectiveness. Irrigation districts are familiar with concrete and can easily perform required maintenance.

   b. Exposed Geomembrane—Exposed geomembranes have excellent effectiveness (90 percent), and the lowest initial construction cost. However, they are susceptible to weathering and damage from animal traffic, construction equipment, and vandalism. Also, irrigation districts cannot readily maintain exposed geomembranes because they are not familiar with geomembrane materials and the special seaming equipment needed to perform repairs.

   c. Concrete with Geomembrane Underliner—The geomembrane underliner provides the water barrier and 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**—The authors are hesitant to draw too many conclusions regarding some of the newest test sections. While some of these test sections look very promising, more time is needed to evaluate them. These test sections include:

   Buried GCL (test section O-1)
   Exposed EVA geocomposite (test section BI-1)

Exposed white HDPE (test section BU-1)
Exposed metallized PE (test section LO-1)
Exposed, wet-applied, polyurethane geocomposite (test section TF-1)

4. **Maintenance**—Through 10 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, 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

The 34 test sections range in age from 1 to 10 years. Reclamation plans to revisit these 34 test sections in another 3 to 5 years to further assess their performance, especially the newest test sections, which have only been through one or two irrigation seasons.

1. Additional Test Sections—Reclamation will continue to collaborate with manufacturers to construct additional test sections to evaluate new materials and techniques. New test sections being considered include Polyacrylamide (PAM), Soil Cement, and bottom-only lining. Reclamation is pursuing a cooperative agreement with Denver Water to construct these test sections on Denver's Highline Canal.

    a. PAM is a spray-applied polymer emulsion than can be applied at very low unit costs. PAM acts as a flocculent and forms a "slime" layer on the canal invert. This layer of polymer slime and flocculated soil particles forms a seal on the canal prism, significantly reducing seepage. The effects of PAM are somewhat temporary, and PAM is usually re-applied once or twice a year. The Uncompaghre Valley Water Users Authority (UVWUA) has been experimenting with PAM, and Reclamation will be assisting UVWUA with a scientific analysis of PAM costs, effectiveness and durability.

    b. Soil Cement is created in the canal prism by in-situ mixing the canal native soils with cement and water. Reclamation is pursuing a cooperative agreement with PCA to research this material.

    c. Bottom-only lining consists of placing a geomembrane on the canal invert and covering it with 6 to 12 inches of soil. The side slopes are left unlined. Pervious research has shown that bottom-only lining can be 20 to 50 percent effective. Bottom-only lining can be cost effective because the bottom is the easiest part of the canal to line. Bottom-only lining is also aesthetically pleasing because the geomembrane is buried in the invert and not visible from the canal bank.

2. Repairs—The irrigation districts often do not have the equipment or expertise to perform repairs on the exposed geomembrane test sections. Reclamation has purchased a small hot-air welder to loan out for making repairs. This small, hand-held welder is suitable for small repairs on most of the exposed geomembranes, including HDPE, LLDPE, PP, and PVC.

3. Addition costs comparisons - to help compare the materials in this study with other lining alterations, additional cost comparisons are needed for traditional lining materials, such as buried pipe and buried geomembranes.

Tulelake Irrigation District - The First

Klamath Falls Field Office was the first Reclamation office to prepare geomembrane canal-lining specifications using this study as a guide. Tulelake Irrigation District (T.I.D.), which is located in the Kalamath River Basin on the Oregon - California border, was declared in extreme drought conditions during the summer of 2001 and did not receive its allotment of irrigation water for that year. To ease the water shortage, irrigation wells were drilled and the water pumped into the canal for delivery to the ranchers. The cost for this water to the Bureau was from as low as $20.00 per acre foot to as high as $55.00 per acre foot. The average cost was $37.50 per acre foot. T.I.D. has a two tiered pricing plan. If irrigation water is delivered as it has been in the past, the rancher would pay an average cost of $14.00 per acre foot.

T.I.D. recognized that water losses due to seepage were a problem. The M-2 Lateral diverts water from the M - Main Canal. Because of the drought in this region, T.I.D. approached Reclamation for assistance with lining a portion the M-2 Lateral. The portion of the lateral that T.I.D. wanted to line was 2.3 miles long, and had a cross section of about 26 feet.

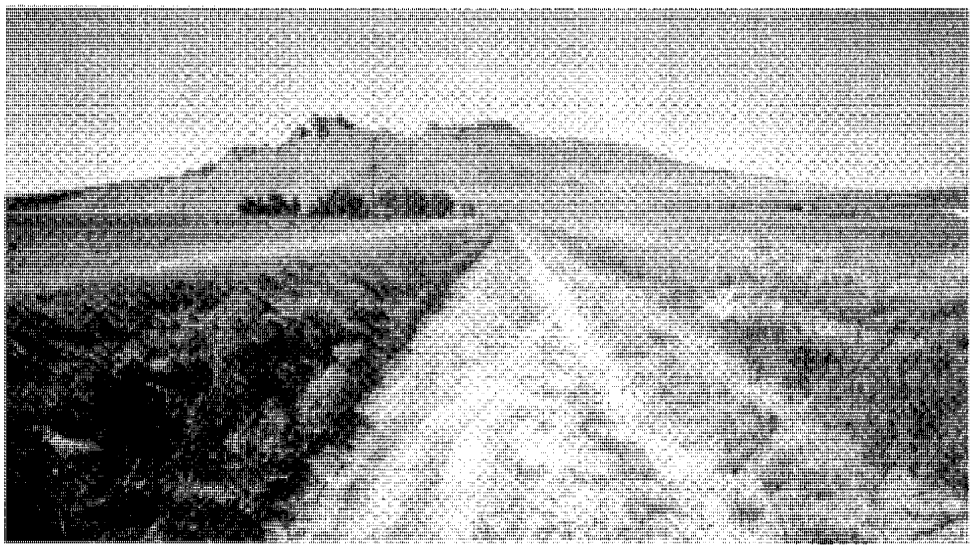
The Klamath Falls Area Office contacted the Pacific Northwest Regional Office Water Conservation Center for assistance. Reclamation met with T.I.D. representatives and convinced them that a geomembrane lining material would work and told them that Reclamation would put out a specification. Materials and training for installation would be provided by the material supplier, and the canal preparation and the labor for installation would be furnished by T.I.D. It was determined by the Procurement Branch in the Mid-Pacific Region that the appropriate way to bid this job would be to use the Simplified Acquisition Procedures. The job description was written and advertised in the Commerce Business Daily. (See appendix F, which includes the notice, the questions asked after the site visit, and sample evaluation sheets.) A site visit was held after release of the advertisement, and questions and answers were fielded at the end of the visit. Nine companies attended the site visit. In all, 12 companies bid on this job. Jim's Water Gardening, of Salem Oregon, was selected to do the work. The geomembrane proposed was a 45-mil EPDM manufactured by Firestone Building Products. Before the material arrived, T.I.D. began preparing the canal using their equipment. When the material arrived at the site, T.I.D. was ready to begin the installation. T.I.D. had about 10 employees, included the heavy equipment operators, available for the installation. When the installation started, T.I.D. was given instructions on how to place the material and seam the panels together. T.I.D. completed the job in about 4 weeks. (This included time that was needed to fix another problem that had occurred).

Reclamation made an assessment of the seepage rate and the B/C ratio for this job. The average seepage rate for this area was estimated to be about 0.65 $ft^3/ft^2/day$. If the cost of water for T.I.D. was $14.00 per acre foot, the B/C ratio was about 1.4; however, if the cost of water was $37.50, which was the current market price, the B/C ratio would be 3.6.

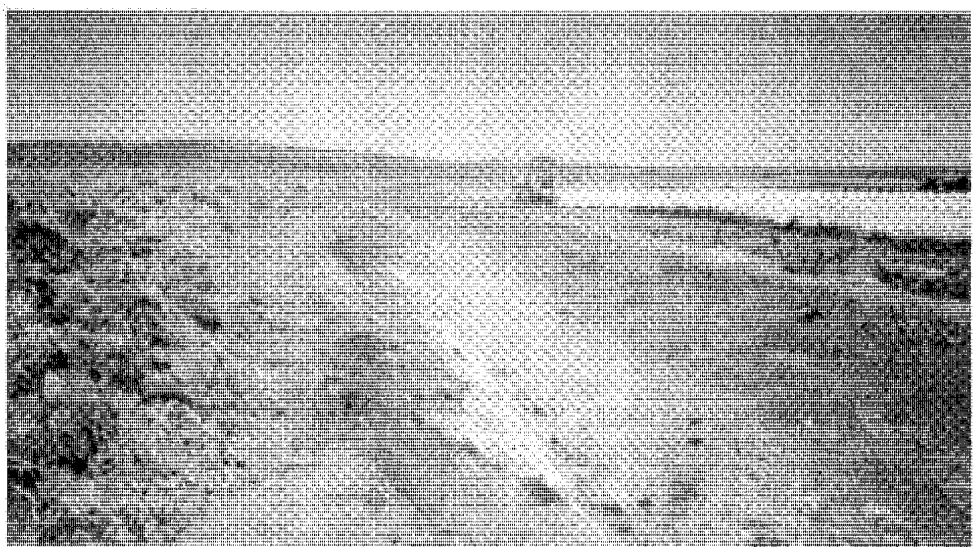
Canal Lining Costs for Tulelake Irrigation District M-2 Lateral

Description	Lining Material				Subgrade Preparation and Installation $ / ft²	Total $ / ft²
	Geomembrane $ / ft²	Geotextile $ / ft²	Shotcrete $ / ft²	Other Cost $ / ft²		
Exposed 45-mil EPDM	$0.27	$0.09			$0.11	$0.47

Tulelake Irrigation District
Exposed 45-mil EPDM Geomembrane

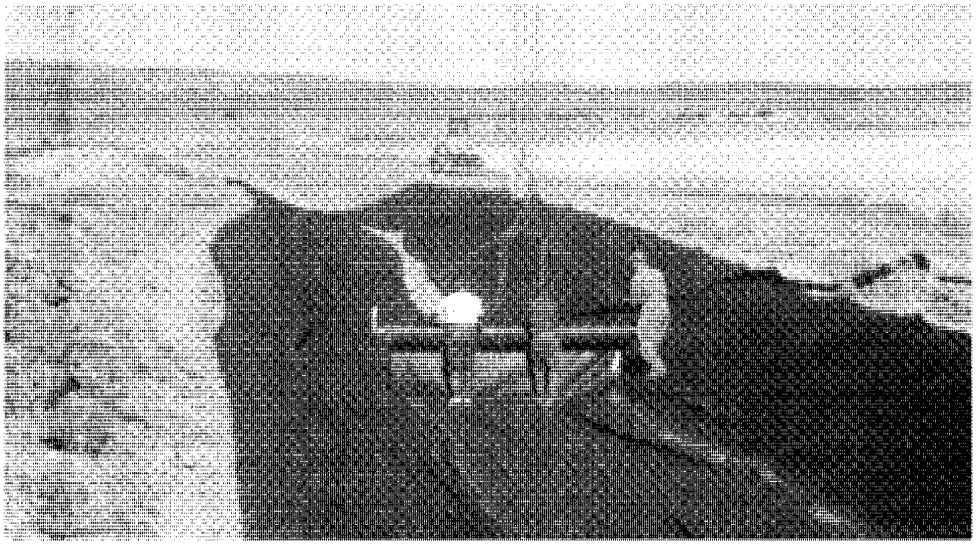


Photograph 1.—M-2 Lateral before lining.

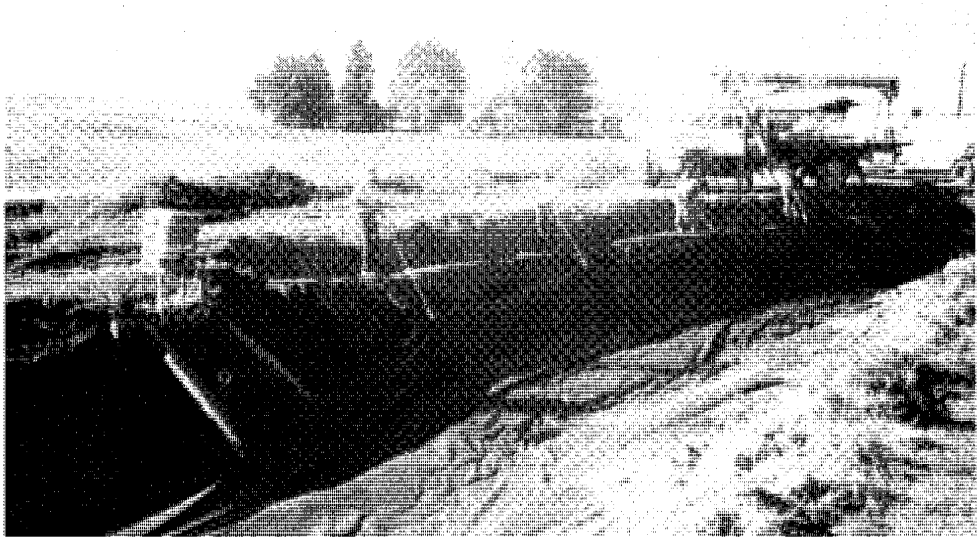


Photograph 2.—M-2 Lateral after shaping.

Tulelake Irrigation District
Exposed 45-mil EPDM Geomembrane

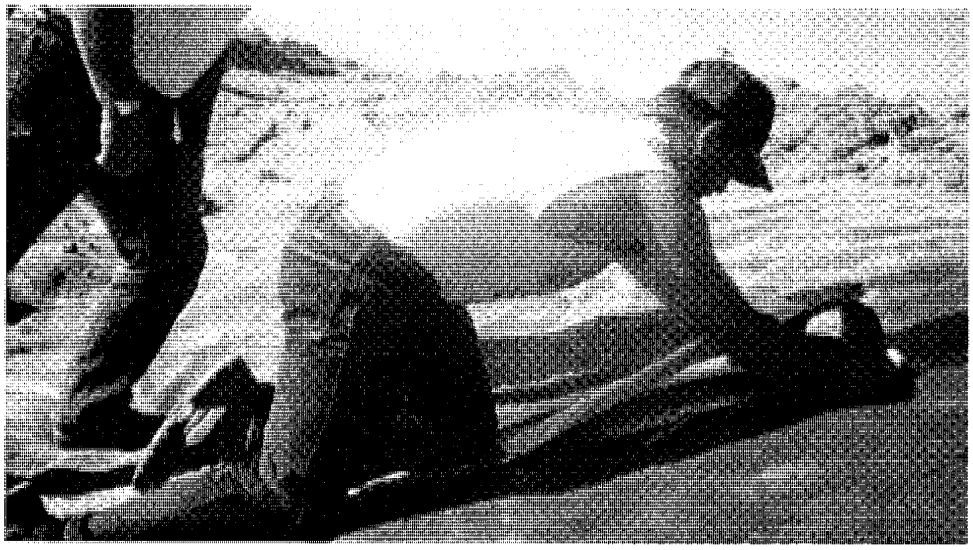


Photograph 3.—Geotextile in place and the geomembrane being place over it.

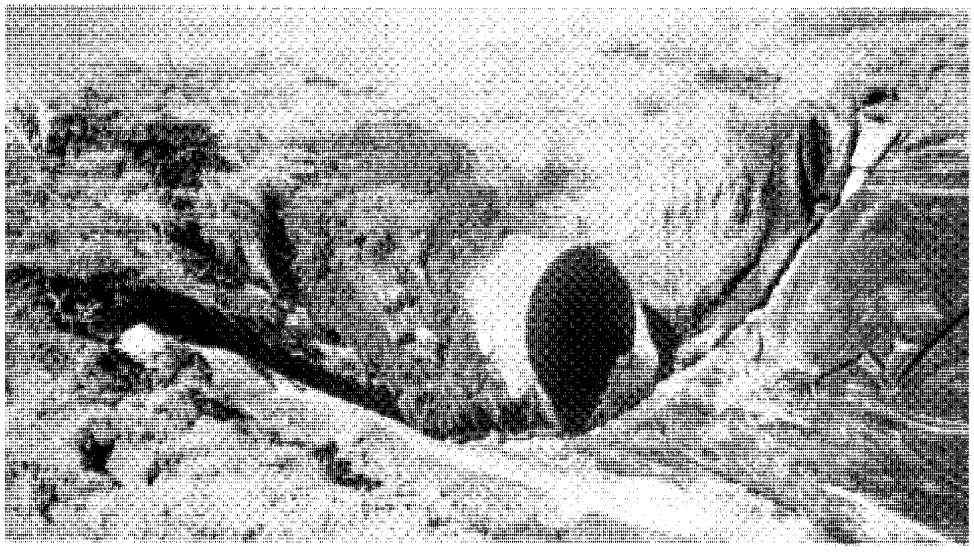


Photograph 4.—Tulelake Irrigation District personnel pulling the lining material up the side slope.

Tulelake Irrigation District
Exposed 45-mil EPDM Geomembrane

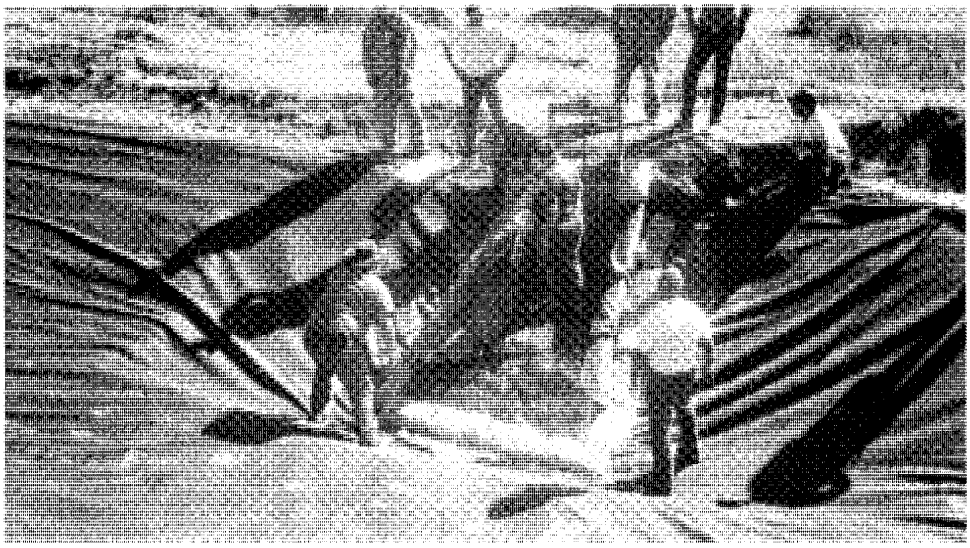


Photograph 5.—T.I.D. personnel seaming the panels using a solvent and a 6-inch wide tape.

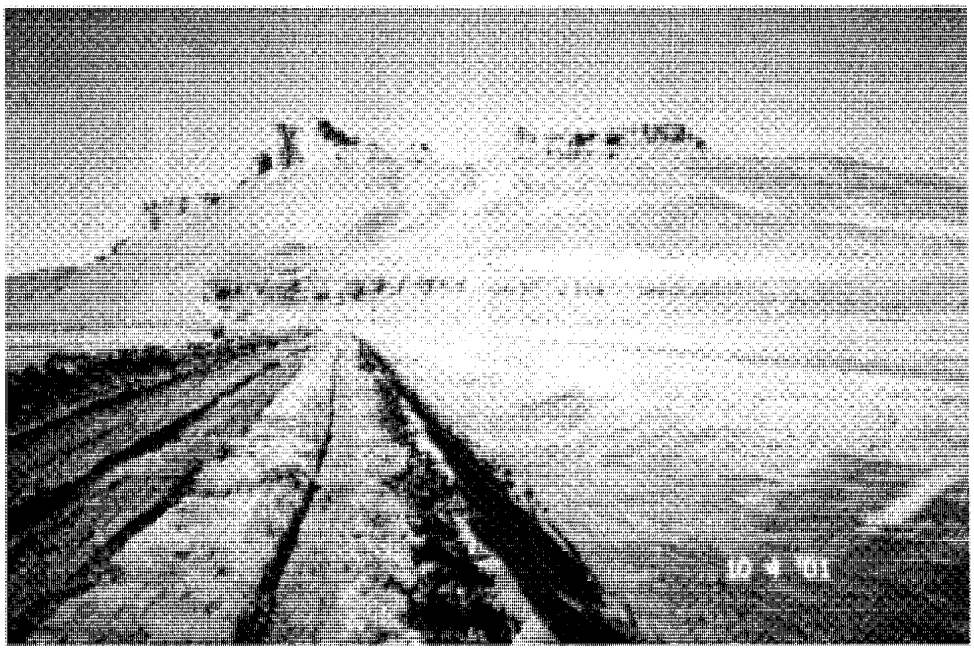


Photograph 6.—View of one of the cutoff trenches. Concrete was placed in the trench dry. As water gets in the bag, the concrete hardens and acts as an anchor.

Tulelake Irrigation District
Exposed 45-mil EPDM Geomembrane



Photograph 7.—View of the cutoff ditch around a turnout structure. The same procedure was used here as in photograph 6.



Photograph 8.—Completed geomembrane installation.

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APPENDICES

APPENDIX A

New Test Sections
Material Data Sheets

Exposed 40-mil Wet-applied Polyurethane Geocomposite
Liquid Polyurethane Resin
Geotextile is Typar 3301 non-woven spunbonded polypropylene geotextile

Exposed 45-mil Reinforced Metallocene (mPE)

Exposed 160-mil Coletanche NTP 2 ES

Exposed 60-mil White Textured HDPE
Geotextile is a 10-oz needle-punched nonwoven (Synthetic Industries 1071)

Exposed 20-mil EVA Geomembrane

TYPAR® 3301 Non-Woven Geotextile

PROPERTY	TEST METHOD	MARV
Grab Tensile Strength (lbs)	ASTM D4632	120
Grab Elongation (%)	ASTM D4632	60
Trapezoid Tear (lbs)	ASTM D4533	35
Puncture (lbs)	ASTM D4833	25
Mullen Burst (psi)	ASTM D3786	90
Permittivity (sec^{-1})	ASTM D4491	0.8
Permeability (cm/sec)	ASTM D4491	0.02
A.O.S. (U.S. Sieve)	ASTM D4751	50
UV Resistance @500 hrs (%)	ASTM D4355	70
Mass/Area (Typical)(oz/sy)	ASTM D5261	3.0
Water Flow Rate (gpm/ft^2)	ASTM D4491	50

Specifications

English

Reinforced Metallocene (mPE)

Serrot's mPE is a reinforced flexible polypropylene geomembrane produced from first quality resins. Serrot mPE contains a weft-inserted, polyester scrim reinforcement, which enhances tear and puncture resistance without reducing environmental stress crack resistance. Such properties make mPE ideal for floating covers and any applications requiring exceptional support in high-tensioned areas. mPE geomembranes are very flexible, durable, and have been formulated to be resistant to chemicals, ultraviolet degradation, and aging. mPE is formulated to be welded directly to HDPE or LLDPE. Serrot mPE is manufactured in black/black and tan/black. [6,7]

Property	Test Method	Frequency[1]	RPP36	RPP45
Thickness (nominal)[2] (mils) Thickness (minimum)[3] (mils)	D751/D5199	per roll	36 34	45 41
Weight per Unit Area (g/sf)	D5261	50,000 SF	68	82
Tensile Properties • Grab Strength (lb/4") • Grab Elongation (%)	D751	50,000 SF	 225 22	 250 22
Tear Resistance[4] (min. ave.) (lb)	D5884 (2 ipm)	50,000 SF	65	65
Ply Adhesion[4] (lb or FTB)	D413	50,000 SF	20	20
Puncture Resistance (min. ave.) (lb)	D4833 FTMS 101B/ Method 2031[5]	50,000 SF Certified	85 200	90 250
Dimensional Stability (max) (%)	D1204	Resin Batch	±1.0	±1.0
Hydrostatic Resistance (psi)	D751 Method A, Proc. 1	Certified	300	350
Low Temp Flexibility	D2136 1/8" Mandrel, 4 Hrs	Certified	-40°F	-40°F
Stress Crack Resistance (hrs)	D1693	Certified	5,000	5,000
UV Resistance (hrs)	QUV	Certified	5,000	5,000
Reinforcing Scrim	9 x 9, 1000 denier weft-inserted polyester for all material thicknesses			

[1]Testing frequencies are rounded to the nearest full roll.
[2]Nominal thickness is based on no coupon being less than 10% under specified thickness. Average thickness may be less than specified thickness.
[3]Minimum thickness is based on average thickness being equal to or greater than specified thickness
[4]Peak value.
[5]FTMS 101b has been replaced with D4833. Value shown for comparison purposes only.
[6]RPP black/black and tan/black is available in accordance with ANSI/NSF 61 standard and can be used for both potable and industrial applications.
[7]Allow four (4) months lead time to fully evaluate long term UV resistance of the color.

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TESTS ON BITUMINOUS GEOMEMBRANE Colétanche NTP 2 ES

Type of test and measured properties	Standard	Unit	Test results
Mass per unit area	ASTM D 5261		
Mass per unit area		g/m²	5306
Nominal thickness	ASTM D 5199		
Nominal thickness at 20 kPa		mm	4.41
Tensile	ISO 1421		
Longitudinal direction			
Break strength		kN/m	26.6
Strain at break		%	61.7
Transversal direction			
Break strength		kN/m	20.5
Strain at break		%	69.3
Tear	ASTM D 751		
Longitudinal direction			
Tear resistance		N	164
Transversal direction			
Tear resistance		N	181
Static puncture (CBR method)	EN ISO 12236		
Puncture strength		kN	3.6
Coefficient of variation		%	4.2
Dimensional stability	ASTM D 1204		
Longitudinal direction			
Size variation		%	- 0.12
Transversal direction			
Size variation		%	- 0.02
Cold bending	UNI 8202/15		
Longitudinal direction			
Upper face			
Lowest temperature (°C) to wrap on a mandrel (ϕ 20 mm)		°C	- 25
Bottom face			
Lowest temperature (°C) to wrap on a mandrel (ϕ 20 mm)		°C	- 15
Transversal direction			
Upper face			
Lowest temperature (°C) to wrap on a mandrel (ϕ 20 mm)		°C	- 25
Bottom face			
Lowest temperature (°C) to wrap on a mandrel (ϕ 20 mm)		°C	- 10
Water vapour transmission	ASTM E 96		
Permeance		g/m² · 24h	0.155
Permeability coefficient		m/s	3.66×10^{-14}

ENEL
RICERCA - POLO IDRAULICO E STRUTTURALE
NUCLEO TERRE, ROCCE E TECNOLOGIE COSTRUTTIVE
(A. Zaninetti)

GSE®

GSE White Textured*

Light Reflective, Textured HDPE Geomembrane

GSE White Textured is the textured version of GSE White*. It is a high quality, high density polyethylene (HDPE) geomembrane with one or two coextruded, textured surfaces. It has a UV-stabilized, white upper surface that is approximately 3 mils (0.125 mm) thick. This layer is part of the total thickness, the remainder of which is a carbon black stabilized primary layer. The light reflective surface improves detection of post-installation damage and reduces heat buildup on the liner by reflecting solar energy. Reducing liner temperature leads to fewer wrinkles and less subgrade desiccation. This textured product provides enhanced interface friction with adjoining materials.

TESTED PROPERTY	TEST METHOD	MINIMUM VALUES		
Thickness, mils (mm)	ASTM D 5994	36 (0.91)	54 (1.4)	72 (1.8)
Density, g/cm^3	ASTM D 1505	0.94	0.94	0.94
Tensile Properties (each direction)[1]	ASTM D 638, Type IV			
Strength at Break, lb/in-width (N/mm)	Dumbell, 2 ipm	60 (11)	90 (16)	120 (21)
Strength at Yield, lb/in-width (N/mm)		84 (15)	130 (23)	173 (30)
Elongation at Break, %	G.L. = 2.0 in (51 mm)	150	150	150
Elongation at Yield, %	G.L. = 1.3 in (33 mm)	13	13	13
Tear Resistance, lb (N)	ASTM D 1004	30 (133)	45 (200)	60 (267)
Puncture Resistance, lb (N)	ASTM D 4833	72 (320)	108 (480)	144 (641)
Carbon Black Content[2], %	ASTM D 1603	2.0	2.0	2.0
Carbon Black Dispersion	ASTM D 5596	Cat. 1 or 2	Cat. 1 or 2	Cat. 1 or 2
Notched Constant Tensile Load[3], hrs	ASTM D 5397, Appendix	400	400	400

REFERENCE PROPERTY	TEST METHOD	NOMINAL VALUES		
Thickness, mils (mm)	ASTM D 5994	40 (1.0)	60 (1.5)	80 (2.0)
Roll Length (approximate), ft (m)		730 (223)	420 (158)	400 (122)
Low Temperature Brittleness, °F (°C)	ASTM D 746, Cond. B	<-107 (<-77)	<-107 (<-77)	<-107 (<-77)
Oxidative Induction Time, minutes	ASTM D 3895, 200 °C Pure O_2, 1 atm	>100	>100	>100
Dimensional Stability (each direction), %	ASTM D 1204, 100 °C, 1 hr	±2	±2	±2

GSE White Textured is available in rolls approximately 22.5 ft (6.9 m) wide and weighing about 3,700 lb (1,678 kg). Other material thicknesses are available upon request.

[1]The combination of stress concentrations due to coextrusion texture geometry and the small specimen size results in large variation of test results. Therefore, these tensile properties are minimum average values.

[2]GSE White Textured may have an overall ash content greater than 3.0% due to the white layer.

[3]Note: NCTL is conducted on representative smooth membrane samples.

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GEOTEX™ NONWOVEN NEEDLEPUNCHED STAPLE FIBER SPECIFICATIONS
(FOR GPD INTERNAL USE ONLY)

			GEOTEX™ 1071			GEOTEX™ 1101		
Physical Properties	**Test Method**	**Units**	**Minimum[2]**	**MARV[2]**	**Typical[1]**	**Minimum[2]**	**MARV[2]**	**Typical[1]**
Mass Per Unit Area	ASTM D5261	oz/yd^2 (g/m^2)	9.6 (325)	10.0 (335)	10.8 (365)	10.0 (335)	10.3 (345)	11.0 (370)
Thickness	ASTM D5199	mils (mm)	95 (2.4)	105 (2.6)	120 (3.0)	100 (2.5)	110 (2.7)	125 (3.1)
Tensile Strength	ASTM D4632	lb (N)	245 (1090)	260 (1155)	285 (1265)	260 (1155)	275 (1220)	300 (1335)
Elongation	ASTM D4632	%	50	50	60	50	50	60
Trapezoidal Tear	ASTM D4533	lb (N)	90 (400)	100 (445)	115 (510)	95 (420)	105 (465)	120 (530)
Mullen Burst	ASTM D3786	psi (kPa)	485 (3340)	520 (3580)	565 (3895)	500 (3445)	535 (3685)	585 (4030)
Puncture Strength	ASTM D4833	lb (N)	170 (755)	180 (800)	200 (890)	150 (665)	170 (755)	190 (845)
AOS	ASTM D4751	US Sieve (mm)	100 (0.150)	100 (0.150)	120 (0.125)	100 (0.150)	100 (0.150)	120 (0.125)
Permittivity	ASTM D4491	sec^{-1}	n/a	1.2	1.5	n/a	1.2	1.4
Permeability	ASTM D4491[4]	cm/sec	n/a	0.30	0.40	n/a	0.30	0.40
Flow Rate	ASTM D4491	gpm/ft^2 (l/m/m^2)	n/a	85 (3460)	100 (4070)	n/a	85 (3460)	100 (4070)
UV Resistance	ASTM D4355	% Retained	n/a	70	n/a	n/a	70	n/a
Wide Width Tensile	ASTM D4595	lb/in (kN/m)	n/a	105 (18.3)	125 (21.8)	n/a	105 (18.3)	125 (21.8)

Notes:

1. Typical value indicates the average or mean value obtained from test data. By definition 50% of all tested values will exceed the mean.
2. MARV indicates minimum average roll value. This is calculated as the mean minus two standard deviations. Statistically, it yields a 97.7% degree of confidence that any samples taken from quality assurance testing will exceed the value reported.
3. Minimum values are calculated as the mean minus three standard deviations. Statistically, it yields a 99.8% degree of confidence that any samples taken from quality assurance testing will exceed the value reported.
4. ASTM D4491 permeability is calculated using typical thickness from the appropriate permittivity.
5. "n/a" indicates data not available.

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9/24/98



GeoComp, Inc.

PRODUCT SPECIFICATION

COMPOSITION: 20 mil EVA Geomembrane
with 8 oz/yd2 PET geotextile bonded to both sides

PRODUCT STYLE: GC-8208VA

PHYSICAL PROPERTIES

PROPERTY	TEST METHOD	UNITS	VALUE	S.I. VALUE	S.I. UNITS
Weight	ASTM D-3776	oz/yd2	40	1333	gm/m2
Thickness	ASTM D-5799	mils	200	5.06	mm
Grab Tensile	ASTM D-4632	lbs	500	2.225	KN
Grab Elongation	ASTM D-4632	%	150	150	%
Wide Width Tensile	ASTM D-4595	f lb/in			
		MD	120	21.06	KN/m
		TD	160	28.02	KN/m
Puncture Strength	ASTM D-4833	lbs	260	1.56	KN
Puncture Strength*	FTM 101 B METHOD 2031	lbs	450	1.973	KN
Trapezoid Tear	ASTM D-4533	lbs	125	0.556	KN
Mullen Burst	ASTM D-3786	psi	700	47.95	KPa

ENDURANCE PROPERTIES

Abrasion Resistance ***	ASTM D-4886/4632	%	70	70	%
U.V. Resistance **	ASTM D-4355	%	70	70	%
Peel Strength	ASTM D-4545	lbs	n/a	n/a	KN

STD. ROLL PUTUP

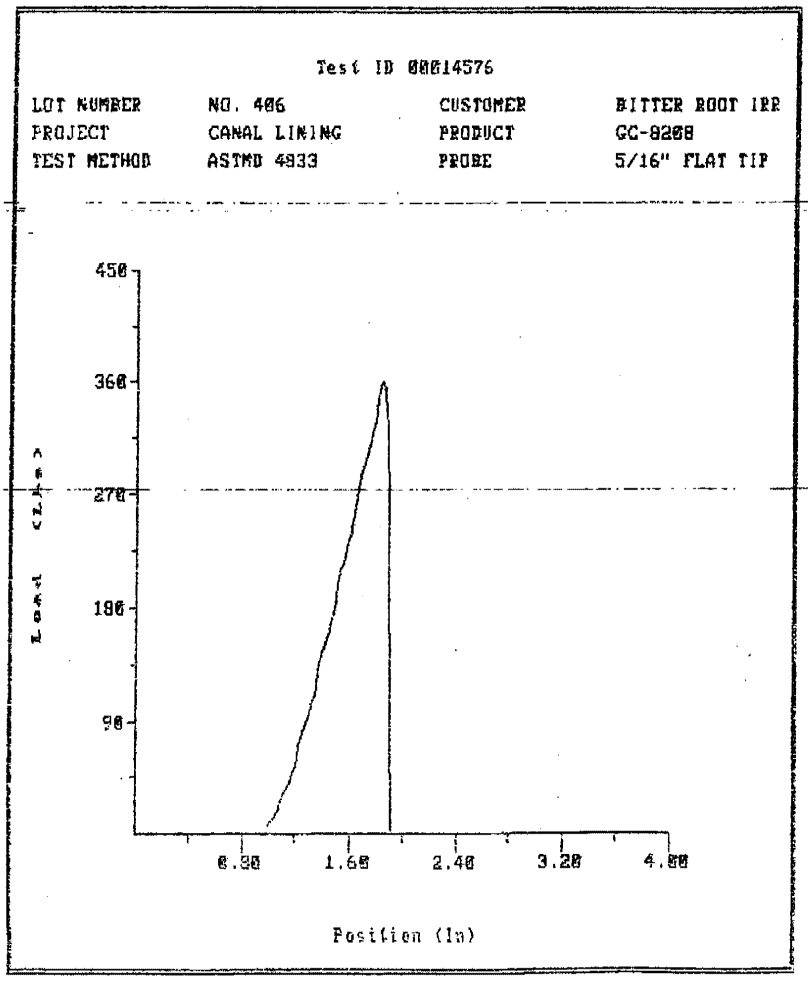
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P.O. Box 2642, Shelby, NC 28151
Phone: (704) 480-7688 FAX: (704) 480-9868 Toll-Free: (800) 846-9446

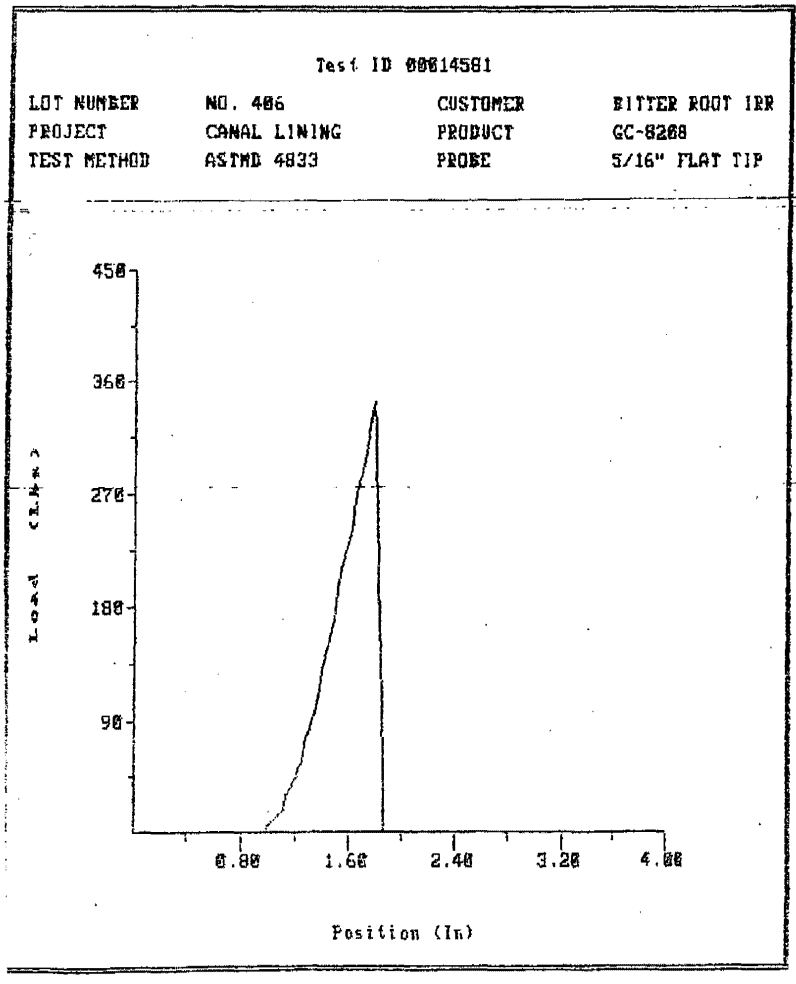
LOT NUMBER	NO. 406	CUSTOMER	BITTER ROOT IRR
F ECT	CANAL LINING	PRODUCT	GC-8208
T METHOD	ASTMD 4833	PROBE	5/16" FLAT TIP

Test ID	00014576		Specimen Area	0.00015400	In^2
Peak Load	361.0	Lbs	Valley Load	-1.0	Lbs
Peak Position	1.902	In	Valley Position	-0.188	In
Peak Stress	2344000	PSI	Valley Stress	-6000	PSI
Test Time	00:00:43				



LOT NUMBER	NO. 406	CUSTOMER	BITTER ROOT IRR
PROJECT	CANAL LINING	PRODUCT	GC-8208
TEST METHOD	ASTMD 4833	PROBE	5/16" FLAT TIP

Test ID	00014581		Specimen Area	0.00015400	In^2
Peak Load	344.0	Lbs	Valley Load	0.0	Lbs
Peak Position	1.855	In	Valley Position	0.000	In
Peak Stress	2234000	PSI	Valley Stress	0	PSI
Test Time	00:00:20				



Appendix B

Laboratory Test Results

Bayer Laboratories

Ditchliner Geotextile/Polyurethane Composite

Polyurethane
Isocyanate Component A

Viscosity @25°C	mPa.s	180
Density @25°C	g/ml	1.24

Polyol Component B

Viscosity @ 25°C	mPa.s	299
Sp. Gr. @ 25°C		1.004

Stoichiometry & Processing Parameters

Mix Ratio		
A-Side	g	41.3
B-side	g	100
Gel Time		adjustable

Geotextile/Polyurethane Composite
Physical Properties

Tensile Strength	psi	1300 - 2000
Elongation	%	45 -65
Puncture Resistance (max. load)	lbs	60 -75
Die C Tear	pli	400 - 500
Split Tear	pli	180 - 240
Peel Strength (concrete)	lbs/in	6 - 8

Appendix C

Laboratory Test Results

Bureau of Reclamation Laboratories

USBR Laboratory Testing of Ditchliner Wet-applied Polyurethane Geocomposite.

Property	Test Method	Value Obtained (Ave. Rolled)	Value Obtained (Ave. Unrolled)
Tensile Strength	ASTM D 882 1 inch samples, 2 ipm	102.2 lb	94.8 lb
Elongation	ASTM D 882	57%	58%
Tensile Stress	ASTM D 882	2221.8 psi	1362.1 psi
Tensile Strength	ASTM D 638 Type IV Dumbbell 2 ipm	18 lb	16.95 lb
Elongation	ASTM D 638	34%	33%
Tensile Stress	ASTM D 638	1555.3 psi	1001.7 psi
Seam Shear	ASTM D 816 2 ipm	56.25 lb	-
Seam Peel	ASTM D 816 2 ipm	1.32 lb	-
Thickness	ASTM D 751	46 mils	70 mil

Appendix D

Deschutes Canal-Lining Demonstration Project

Coupon Test Results

Deschutes Canal-Lining Demonstration Project
80-mil Textured HDPE

Table D-1.—Above the Water-Line

Physical Property	Direction	Mfr Published MARV	USBR Test Results		
			Virgin	Aged	% Change
Yield Strength (lbs/inch)	Machine	168	210	222	+ 6 %
	X-Machine			213	+ 1 %
Yield-Elongation (%)	Machine	13	10	10	0
	X-Machine			10	0
Break Strength (lbs/inch)	Machine	46	233	198	- 15 %
	X-Machine			152	- 35 %
Break-Elongation (%)	Machine	100	428	322	- 25 %
	X-Machnie			32	- 93 %
Tear	Machine	60	69	66	- 4 %
	X-Machine			66	- 4 %

Table D-2.—Below the Water-Line

Physical Property	Direction	Mfr Published MARV	USBR Test Results		
			Virgin	Aged	% Change
Yield Strength (lbs/inch)	Machine	168	210	213	+ 1 %
	X-Machine			214	+ 1 %
Yield-Elongation (%)	Machine	13	10	10	0
	X-Machnie			10	0
Break Strength (lbs/inch)	Machine	46	233	220	- 6 %
	X-Machine			197	- 15 %
Break-Elongation (%)	Machine	100	428	416	- 3 %
	X-Machnie			328	- 23 %
Tear	Machine	60	69	67	- 3 %
	X-Machine			67	- 3 %

Deschutes Canal-Lining Demonstration Project
30-mil PVC with Bonded Geotextile

Table D-3.—Above the Water-Line

Physical Property	Direction	Mfr Published Typical	USBR Test Results		
			Virgin	Aged	% Change
Tensile (lbs/inch)	Machine	121	82	105*	+ 28 %
	X-Machine	95		86	+ 5 %
Elongation (%)	Machine	570	440	117	- 74 %
	X-Machnie	545		225	- 49 %
100 % Modulus	Machine	81	44	105	+ 138 %
	X-Machine	87		81	+ 84 %
Tear	Machine	29		32	+ 10 %
	X-Machine	22		33	+ 50 %
Low Temp Brittleness		Pass @ -20°F		Fail @ + 10°F	> 30°F

* Maximum tensile occurred at yield (54 % elongation) - not at break

Table D-4.—Below the Water-Line

Physical Property	Direction	Mfr Published Typical	USBR Test Results		
			Virgin	Aged	% Change
Tensile (lbs/inch)	Machine	121	82	113*	+ 37 %
	X-Machine	95		96*	+ 17 %
Elongation (%)	Machine	570	440	143	- 68 %
	X-Machnie	545		181	- 59 %
100 % Modulus	Machine	81	44	113	+ 157 %
	X-Machine	87		96	+ 118 %
Tear	Machine	29		19	- 34 %
	X-Machine	22		35	+ 60 %

* Maximum tensile occurred at yield (approx 70 % elongation) - not at break

Deschutes Canal-Lining Demonstration Project
45-mil Hypalon

Table D-5.—Above the Water-Line

Physical Property	Direction	Mfr Published MARV	USBR Test Results		
			Virgin	Aged	% Change
Tensile (lbs/inch)	Machine	250	297	347	+ 17 %
	X-Machine			333	+ 12 %
Tear	Orig	90	95	31	- 67 %
	After Aging	35	---	31	- 11 %
Ply Adhesion (lbs/inch)	Machine	8		8.6	+ 8 %
	X-Machine				
Low Temp (-40 F)	Machine	Pass		Pass	
	X-Machine				

Table D-6.—Below the Water-Line

Physical Property	Direction	Mfr Published MARV	USBR Test Results		
			Virgin	Aged	% Change
Tensile (lbs/inch)	Machine	250	297	338	+ 14 %
	X-Machine			323	+ 9 %
Tear	Orig	90	95	62	- 35 %
	After Aging	35	---	62	+ 77 %
Ply Adhes (lbs/inch)	Machine	8		9.3	+ 16 %
	X-Machine				
Low Temp (-40 F)	Machine	Pass		Pass	
	X-Machine				

Deschutes Canal-Lining Demonstration Project
36-mil Hypalon

Table D-7.—Above the Water-Line

Physical Property	Direction	Mfr Published MARV	USBR Test Results		
			Virgin	Aged	% Change
Tensile (lbs/inch)	Machine	200	280	277	- 1 %
	X-Machine			273	- 3 %
Tear	Original	80	58	29	- 64 %
	After Aging	35	---	29	- 17 %
Ply Adhesion (lbs/inch)	Machine	8		8.5	+ 6 %
	X-Machine				
Low Temp (-40 F)	Machine	Pass		Pass	
	X-Machine				

Table D-8.—Below the Water-Line

Physical Property	Direction	Mfr Published MARV	USBR Test Results		
			Virgin	Aged	% Change
Tensile (lbs/inch)	Machine	200	280	323	+ 15 %
	X-Machine			314	+ 12 %
Tear	Original	80	58	33	- 59 %
	After Aging	35	---	33	- 6 %
Ply Adhesion (lbs/inch)	Machine	8		8.4	+ 5 %
	X-Machine				
Low Temp (-40 F)	Machine	Pass		Pass	
	X-Machine				

Deschutes Canal-Lining Demonstration Project
45-mil EPDM

Table D-9.—Above the Water-Line

Physical Property	Direction	Mfr Published MARV	USBR Test Results		
			Virgin	Aged	% Change
Tensile (lbs/inch)	Machine	50	57	60	+ 5 %
	X-Machine			63	+ 11 %
Elongation (%)	Machine	500	614	452	- 26 %
	X-Machnie			423	- 31 %
Tear	Machine	9	18	9.5	- 48 %
	X-Machine			8.7	- 52 %

Table D-10.—Below the Water-Line

Physical Property	Direction	Mfr Published MARV	USBR Test Results		
			Virgin	Aged	% Change
Tensile (lbs/inch)	Machine	50	57	61	+ 7 %
	X-Machine			61	+ 7 %
Elongation (%)	Machine	500	614	488	- 21 %
	X-Machnie			419	- 32 %
Tear	Machine	9	18	8.9	- 51 %
	X-Machine			9.1	- 49 %

Deschutes Canal-Lining Demonstration Project
30-mil LLDPE

Table D-11.—Above the Water-Line

Physical Property	Direction	Mfr Published MARV	USBR Test Results		
			Virgin	Aged	% Change
Tensile (lbs/inch)	Machine	114	165	154	- 7 %
	X-Machine		151	147	- 3 %
Elongation (%)	Machine	800	698	704	+ 1 %
	X-Machnie		688	691	~~0~~
Tear	Machine	16	23	21	- 9 %
	X-Machine		26	23	- 12 %

Table D-12.—Below the Water-Line

Physical Property	Direction	Mfr Published MARV	USBR Test Results		
			Virgin	Aged	% Change
Tensile (lbs/inch)	Machine	114	165	149	- 10 %
	X-Machine		151	135	- 11 %
Elongation (%)	Machine	800	698	713	+ 2 %
	X-Machnie		688	639	- 7 %
Tear	Machine	16	23	21	- 9 %
	X-Machine		26	22	- 15 %

Drexel UNIVERSITY

Geosynthetic Research Institute
475 Kedron Avenue
Folsom, PA 19033-1208 USA
TEL (610) 522-8440
FAX (610) 522-8441

October 3, 2002

Mr. Jay Swihart
U.S. Bureau of Reclamation
P.O. Box 25007, DFC Attn. D-8180
Denver, CO 80225

Re.: 10-year textured HDPE geomembranes

Dear Jay,

Enclosed please find the melt index (MI) and oxidative induction time (OIT) results of three textured HDPE geomembrane samples which are coded as "T", "B" and "O". "T" refers to samples taken from above water line, "B" for below water line and "O" for the original.

The MI values are largely the same after 10 year service regardless the exposure environment. However, we are surprise to see the small difference in the OIT values between samples from above and below water line. The OIT curves of "T" and "B" samples are significantly different. For the "T" samples, there is a long graduate increase in the energy followed by a strong exothermal peak. In contrast, the "B" samples exhibit a sharp exothermal peak. We suspect that there are two types of antioxidants added to the geomembrane. One of the antioxidants has been gradually consumed during the 10-year service time. Overall, the textured HDPE geomembrane still contain fair amount of antioxidants and probably can maintain its mechanical property for another 10-years. However, it would be beneficial to have these two properties being evaluated again after 10-years.

If you have any questions, please don't hesitate to contact me.

Truly yours,

Grace Hsuan, Ph.D.
Associate Professor
Civil and Architectural Engineering

cc. Dr. Robert Koerner
Director of GSI

Table 2 - Oxidative Inductive Time Test according to ASTM D3895

Sample Code	Test	OIT (min)	Avarage OIT (min)
T	1	49.9	47.1
	2	39.9	
	3	51.5	
B	1	56.3	55.9
	2	55.6	
O	1	69.6	73.1
	2	76.7	

Table 2 - Melt Index Test according to ASTM D

Sample: Bureau of Reclamation

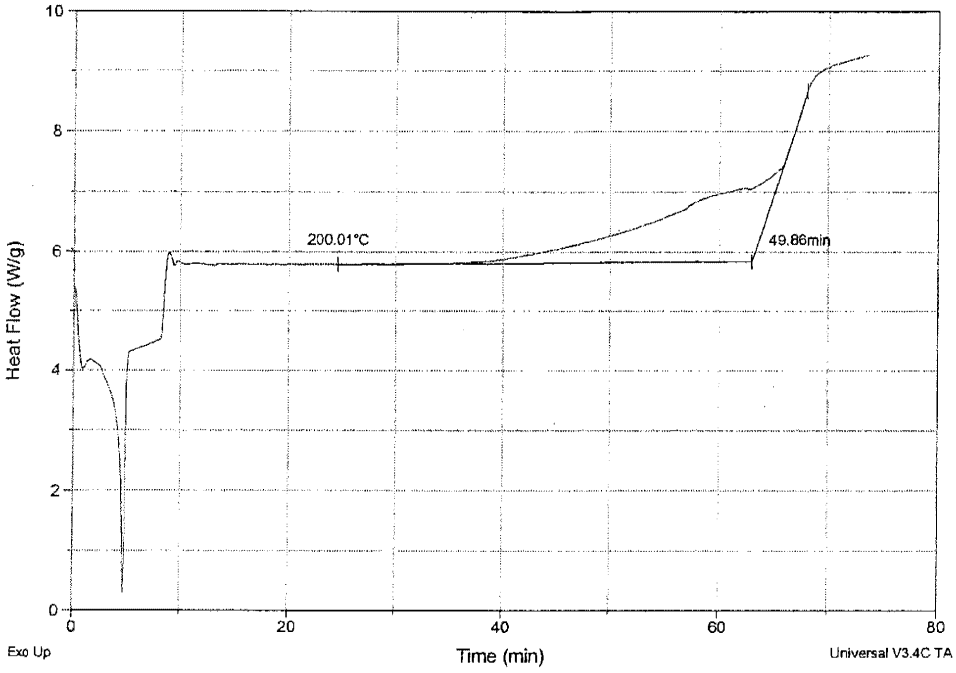
Recorded by: Jingyu Zhang Date: Aug 16, 02

Sample Code	Specimen	Cut No.	Mass (g)	MFR (g/10min)	Average MFR (g/10min)
T	I	1	0.08	0.13	**0.13**
		2	0.08	0.13	
		3	0.08	0.13	
	II	1	0.08	0.13	
		2	0.08	0.13	
		3	0.08	0.13	
B	I	1	0.08	0.13	**0.13**
		2	0.08	0.13	
		3	0.08	0.13	
	II	1	0.08	0.13	
		2	0.09	0.15	
		3	0.08	0.13	
O	I	1	0.09	0.15	**0.14**
		2	0.08	0.13	
		3	0.08	0.13	
	II	1	0.09	0.15	
		2	0.08	0.13	
		3	0.09	0.15	

Sample: Bureau of Reclamation HDPE GM
Size: 3.1000 mg
Method: Oxygen Induction Time
Comment: Bureau of Reclamation HDPE GM 10years _Top the waterline

DSC

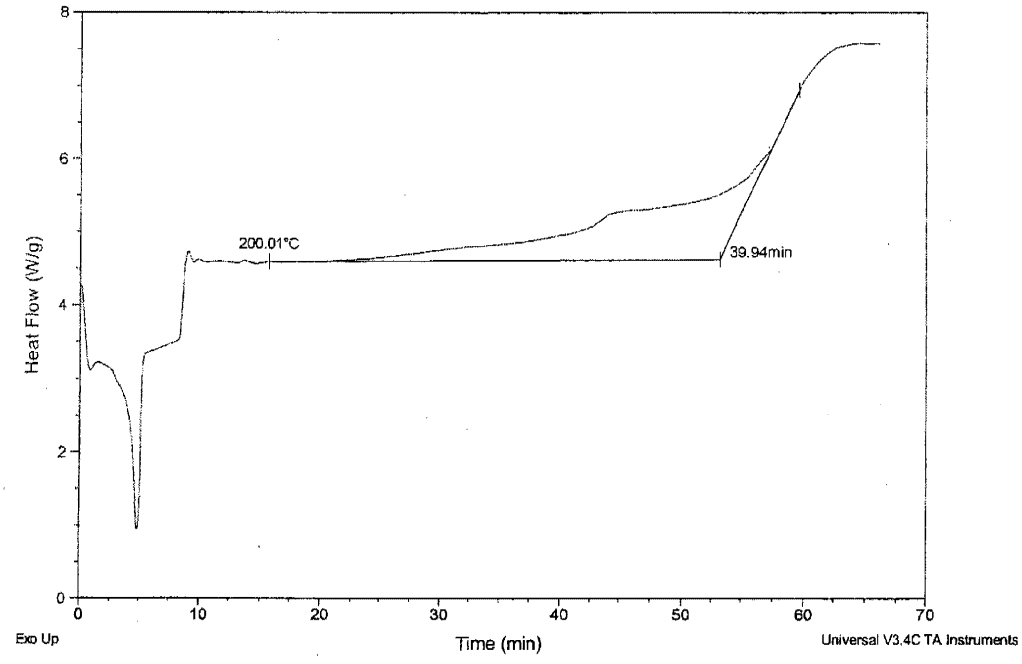
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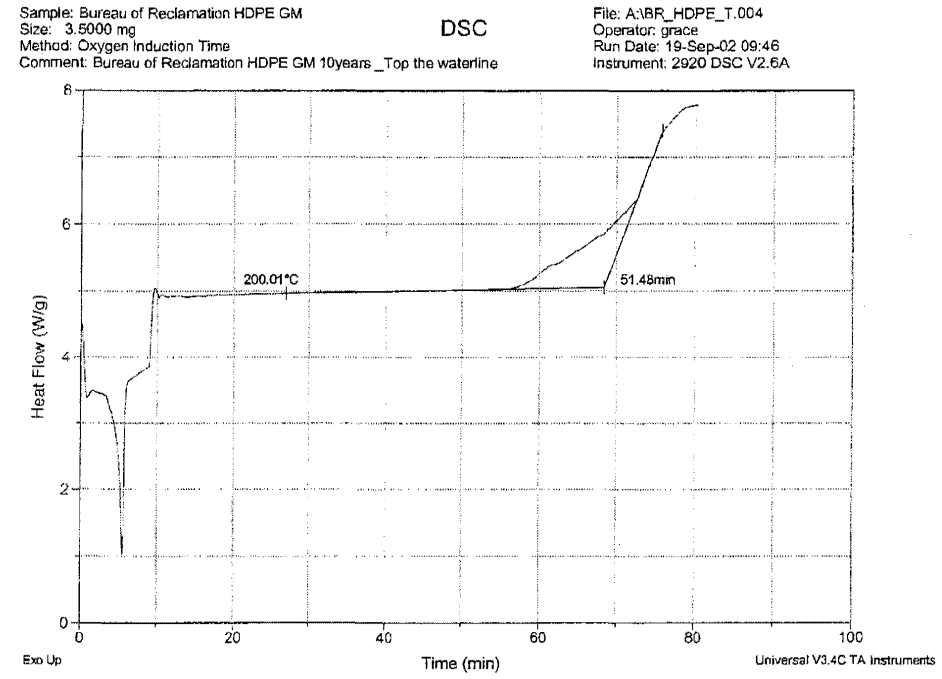


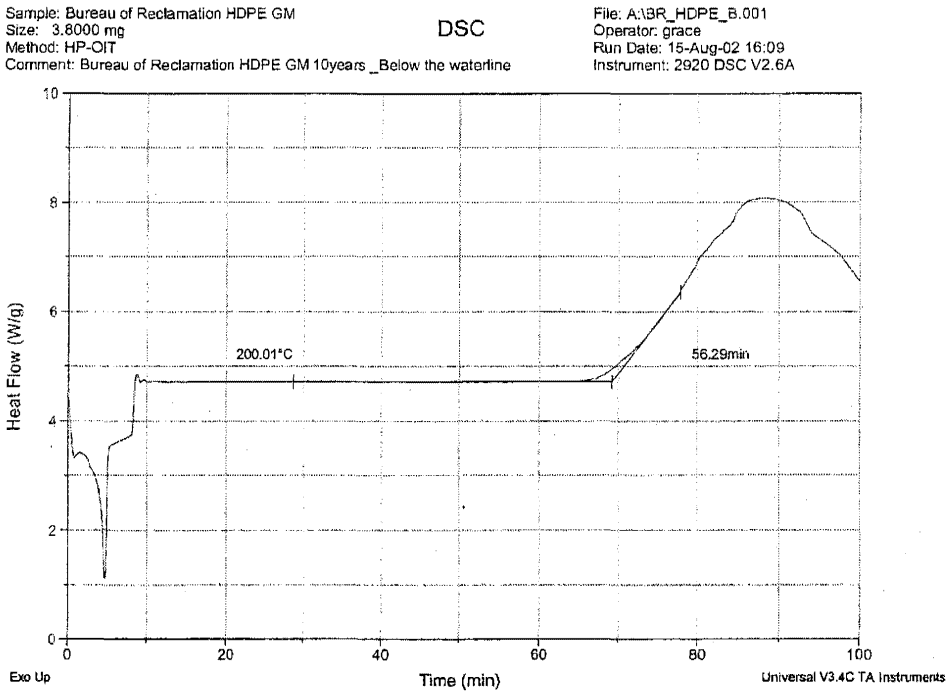
Sample: Bureau of Reclamation HDPE GM
Size: 3.9000 mg
Method: HP-OIT
Comment: Bureau of Reclamation HDPE GM 10years _Top the waterline

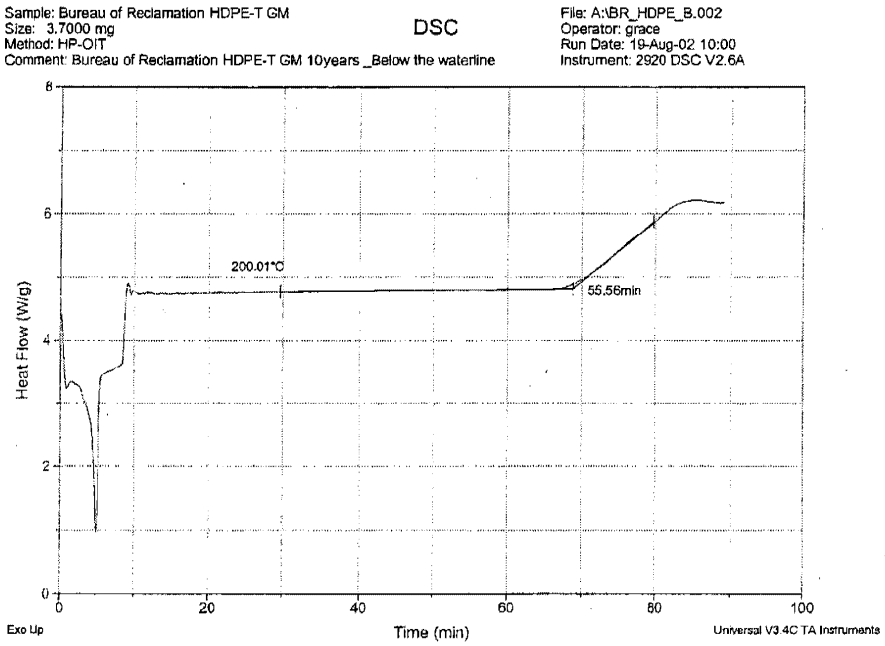
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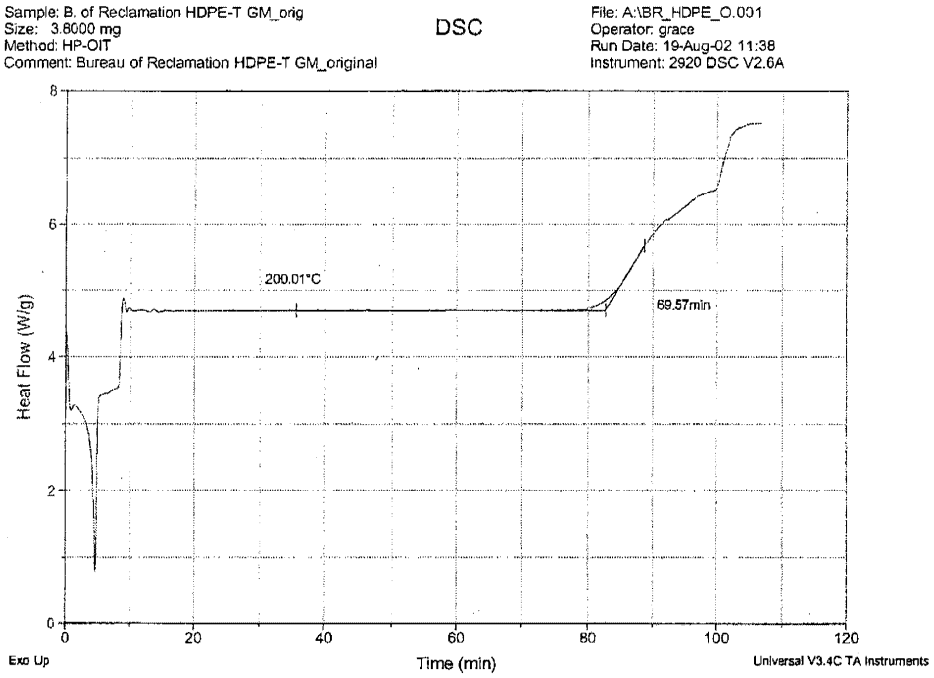
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Run Date: 15-Aug-02 14:53
Instrument: 2920 DSC V2.6A

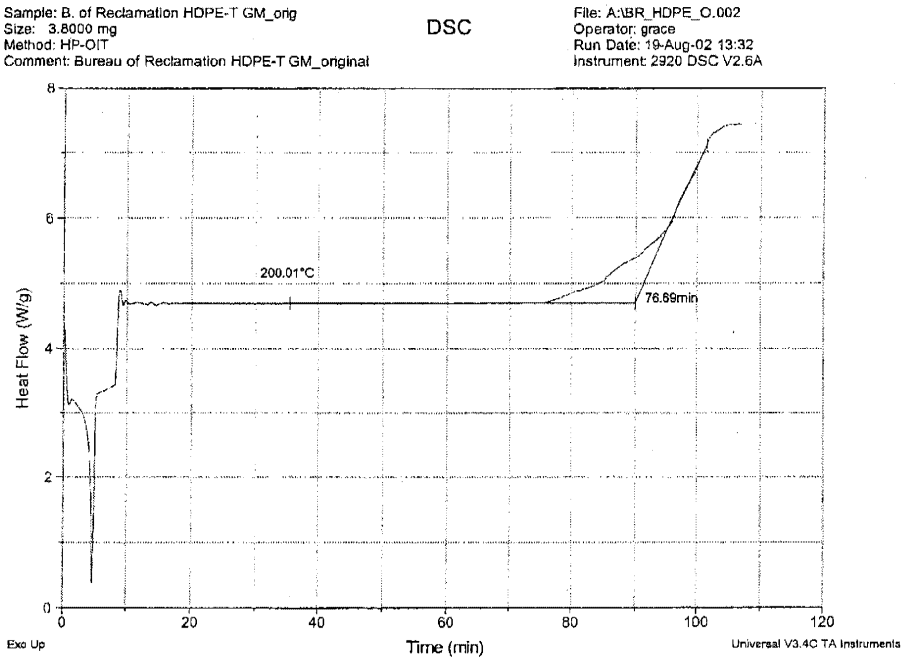



Sample: Bureau of Reclamation HDPE GM
Size: 3.5000 mg
Method: Oxygen Induction Time
Comment: Bureau of Reclamation HDPE GM 10years _Top the waterline
DSC
File: A:\BR_HDPE_T.004
Operator: grace
Run Date: 19-Sep-02 09:46
Instrument: 2920 DSC V2.6A
200.01°C
51.48min
Heat Flow (W/g)
Time (min)
Exo Up
Universal V3.4C TA Instruments


Sample: Bureau of Reclamation HDPE GM
Size: 3.8000 mg
Method: HP-OIT
Comment: Bureau of Reclamation HDPE GM 10years _Below the waterline
DSC
File: A:\BR_HDPE_B.001
Operator: grace
Run Date: 15-Aug-02 16:09
Instrument: 2920 DSC V2.6A
200.01°C
56.29min
Heat Flow (W/g)
Time (min)
Exo Up
Universal V3.4C TA Instruments


Sample: Bureau of Reclamation HDPE-T GM
Size: 3.7000 mg
Method: HP-OIT
Comment: Bureau of Reclamation HDPE-T GM 10years _Below the waterline
DSC
File: A:\BR_HDPE_B.002
Operator: grace
Run Date: 19-Aug-02 10:00
Instrument: 2920 DSC V2.6A
200.01°C
55.56min
Heat Flow (W/g)
Time (min)
Exo Up
Universal V3.4C TA Instruments


Sample: B. of Reclamation HDPE-T GM_orig
Size: 3.6000 mg
Method: HP-OIT
Comment: Bureau of Reclamation HDPE-T GM_original
DSC
File: A:\BR_HDPE_O.001
Operator: grace
Run Date: 19-Aug-02 11:38
Instrument: 2920 DSC V2.6A
200.01°C
69.57min
Heat Flow (W/g)
Time (min)
Exo Up
Universal V3.4C TA Instruments


Sample: B. of Reclamation HDPE-T GM_orig
Size: 3.8000 mg
Method: HP-OIT
Comment: Bureau of Reclamation HDPE-T GM_original
DSC
File: A:\BR_HDPE_O.002
Operator: grace
Run Date: 19-Aug-02 13:32
Instrument: 2920 DSC V2.6A
200.01°C
76.69min
Heat Flow (W/g)
Time (min)
Exo Up
Universal V3.4C TA Instruments

Appendix E

Benefit/Cost Ratio

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

B/C = 3.66

Appendix F

Tulelake Irrigation District

CBDNet

CBD Search Results

Click on the headline for the full-text of the notice. Click on the to view the notice in a new window to help you compare two notices.

Search Database:

CBD - Archive of Notices

For: "CANAL LINING MATERIALS"

Total Hits: 40

[1]
CBD [Posted May 21, 2001]: 84--COLD WEATHER GEAR
Size: 12881 bytes, **Relevance Score:** 1000

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[2]
CBD [Posted June 2, 2000]: A--MATERIALS PROGRAM
Size: 11373 bytes, **Relevance Score:** 816

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[3]
CBD [Posted January 13, 1999]: 61--MPA TOWER LIGHTING PROJECT
Size: 12402 bytes, **Relevance Score:** 805

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[4]
CBD [Posted June 25, 2001]: 99--CANAL LINING MATERIAL
Size: 9905 bytes, **Relevance Score:** 644

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[5]
CBD [Posted June 25, 2001]: 99--CANAL LINING MATERIAL
Size: 9905 bytes, **Relevance Score:** 644

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[6]
CBD [Posted October 13, 1999]: 84--OXFORD SHOES
Size: 5749 bytes, **Relevance Score:** 635

[Commerce Business Daily: Posted in CBDNet on June 25, 2001]
[Printed Issue Date: June 27, 2001]
From the Commerce Business Daily Online via GPO Access
[cbdnet.access.gpo.gov]

PART: U.S. GOVERNMENT PROCUREMENTS
SUBPART: SUPPLIES, EQUIPMENT AND MATERIAL
CLASSCOD: 99--Miscellaneous
OFFADD: U.S. Bureau of Reclamation, Mid-Pacific Region, Attention: MP-3810, 2800 Cottage Way, Room E-1815, Sacramento, CA 95825-1898
SUBJECT: 99--**CANAL LINING** MATERIAL
SOL 01SQ202159
DUE 072401
POC Ms. Debra Keith (916) 978-5135
DESC: (i) This is a combined synopsis/solicitation for commercial items prepared in accordance with the format in the Federal Acquisition Regulation (FAR) 12.6, as supplemented with additional information included in this notice. This announcement constitutes the only solicitation; proposals are being requested and a written solicitation will not be issued. PAPER COPIES OF THIS SOLICITATION WILL NOT BE AVAILABLE. The solicitation will be issued on the World Wide Web and can be found at the following web site: FedBizOpps.Gov. (ii) Solicitation 01SQ202159 is issued as a Request for Quote (RFQ). Written documentation will not be issued for this quote. (iii) The solicitation is being conducted under Simplified Acquisition Procedures (SAP) FAR Part 12 and 13. The solicitation document, incorporated provisions and clauses are those that are in effect through Federal Acquisition Circular (FAC) 97-24 and Defense Federal Acquisition Regulation Supplement, Defense Change Notice (DCN) 20001213. It is the contractors responsibility to be familiar with applicable clauses and provisions. (iv) This acquisition will be 100% small business set-aside. The North American Industrial Classification (NAIC) Code is 561621 with a size standard $11.5M. (v) The Bureau of Reclamation has a requirement to improve **canal** efficiencies. Seepage losses in canals can range from 10 to 50 percent of their irrigation water, with the most severe (angular) soil conditions accounting for the highest seepage rates and the most challenging design. Much of this seepage water is lost to beneficial use. **Canal-lining** technologies are needed that can minimize seepage losses at reasonable costs. Low-tech **lining** systems that can be installed by irrigation districts offer the most promise. Material will be subject to UV exposure, animals, and other natural elements. Reclamation is seeking proposals from material suppliers to provide geomembrane, geotextile cushion, and on-site technical assistance for installation and seaming. The Tulelake Irrigation District (District) will perform subgrade preparation and installation, and seaming that they are qualified to undertake. The contractor shall provide seaming equipment and shall perform all seaming that is normally performed by personnel specially trained and certified for such work. The installation and seaming work that the District is qualified to perform will be performed by 10 laborers working a normal work week of four days in 10 hour shifts. (vi) The M-2 Lateral **lining** reach starts Sta. 2+50 and extends to Sta. 121+92 (2.3 miles) and is about 30 feet wide. The lower reach has some small rocky outcrops which may require a geotextile for cushioning. The price quote for this procurement shall be divided into the following commercial items, Contract Line item number (CLIN) - CLIN 0001 **Canal Lining** Material 400,000 square feet. The maximum panel size shall be limited to 30 feet by 200 feet and the minimum ?mil? thickness of the geomembrane shall be 45 mils; CLIN 0002 Geotextile 100,000 square feet with a minimum weight of 10 oz/yd2; CLIN 0003 Seaming Equipment,

The geomembrane manufacturer shall provide two (2) new seaming machines for installation and repairs; CLIN 0004 Geomembrane Lifting Bar, The geomembrane manufacturer shall supply a lifting bar which will be returned to the contractor by January 1, 2002. CLIN 0005 Geomembrane Manufacturer Seaming Technicians, The geomembrane manufacturer may bid on providing it?s own seaming experts, but must still provide training to Reclamation for repairs and provide equipment to do so. Contractor?s proposals which provide for their own specialized staff to perform seaming work shall be required to abide by the requirements of the U.S. Bureau of Reclamation?s Safety and Health Standards; CLIN 0006 Technical Expert, The geomembrane manufacturer will provide a minimum of four (4) to five (5) days of on-site technical assistance for installation, seaming and making repairs; (vii) Delivery: Date of delivery of **materials** shall be by NLT October 01, 2001. Delivery will be quoted as FOB Destination to 2717 Havlina Rd., Tulelake, CA, 96134. (viii) The following FAR provisions and clauses are applicable to this procurement: 52.212-1, Instructions to Offerors _ Commercial Items (OCT 2000) is hereby incorporated by reference. Site visit: Prospective Contractors are strongly advised to attend the site visit scheduled for July 17, 2001 @ 10:00 AM, Tulelake Irrigation District, 2717 Havlina Rd, Tulelake, CA 96134. Coordination must be done with POC Jerry Townsend , 514-883-6935, in advance of site visit to identify visitors by name. Site for installation will be addressed during the site visit and a question and answer session will be conducted at the end of the site visit. Offers must be itemized and individually priced according to CLIN numbers and include legible descriptive literature for items for evaluation purposes. (ix) Solicitation provision at FAR 52.212-2, Evaluation _ Commercial Items (JAN 1999), is hereby incorporated by reference. Evaluation _ Commercial Items (JAN 1999) (a) The Government will award a purchase order resulting from this solicitation to the responsible offeror whose offer, conforming to the solicitation, will be the most advantageous to the Government, price and other factors considered. The Government intends to evaluate quotes and award a contract without discussions with offerors. The Government reserves the right to conduct discussions if the Contracting Officer later determines them to be necessary. Evaluation factors other than cost or price when combined are approximately equal to cost or price. The following evaluation factors shall be used to evaluate offers: (i) technical capability - (a) ease of installation (b) damage resistance (c) ease of repair (d) expected life (e) seepage control; and descriptive literature of the items offered to meet the government requirement, (ii) past performance, and (iii) price. The Government reserves the right to evaluate technical compliance and price to make a best value decision. This could result in award to other than the lowest price offer. The technical evaluation will consist of reviewing and evaluating technical and price aspects of the contractors proposal. If the offeror fails to provide the descriptive literature, the offeror could be deemed non-responsive and therefor no award made to that contractor. (x) Offerors are reminded to include a completed copy of the provision at 52.212-3, offeror Representations and Certifications--Commercial Items (APR 2001) and 252.212-7000, Offeror Representations and Certifications--Commercial Items (NOV 1995), with his/her offer. A copy of the Certifications and Representations can be found at the following web site: http://www.arnet.gov. (xi) Clause 52.212-4, Contract Terms and Conditions- Commercial Items, applies to this acquisition. (xii) Clause 52.212-5 Contract Terms and Conditions Required to Implement Statutes or Executive Orders--Commercial Items (Deviation) applies to this acquisition. The following clauses are applicable to this acquisition: 52.222-3,

Convict Labor; 52.233-3; Protest After Award; 52.232-33; Payment by Electronic Funds Transfer Central Contractor Registration; 52.247-34, F.O.B. Destination; 52.252-2, Clauses Incorporated by Reference; 52.252-6, Authorized Deviation In Clauses; 252.212-7001, Contract Terms and Conditions Required to Implement Statutes or Executive Orders Applicable to Defense Acquisitions Of Commercial Items (Deviation); 252.204-7003, Control of Government Personnel Work Product; 252.204-7004, Required Central Contractor Registration; 52.253-1, Computer Generated Forms; 52.211-17, Delivery of Excess Quantities; 52.222-26, Equal Opportunity; 52.222-35, Affirmative Action For Disabled Veterans and Veterans of the Vietnam Era; 52.222-36, Affirmative Action for Workers With Disabilities; 52.222-37, Employment Reports on Disabled Veterans and Veterans of the Vietnam Era; 52.222-21, Prohibition of Segregated Facilities; 52.222-22, Previous Contracts and Compliance Reports are hereby incorporated by reference. For full text of these clauses refer to http://arnet.gov/far (xiii) N/A (xiv) N/A (xv) N/A (xvi) This announcement will close and written quotes are due by July 24 , 2001. Signed and dated offers, to include a complete listing of all items, must be submitted to the Contracting Officer, Bureau of Reclamation, 2800 Cottage Way, RM-E1815, Sacramento, California 95825-1898. Responsible sources may submit a quote which shall be considered. No faxed quotes will be accepted. Should you have any questions regarding this procurement, please phone Debra Keith, Contract Specialist at (916) 978-5135.
LINKURL: http://ideasec.nbc.gov/ecprod/owa/ecmenu$.firstcount/
LINKDESC: For more information
EMAILADD: dkeith@mp.usbr.gov
EMAILDESC: Contract Specialist
CITE: (W-176 SN50P9F3)

Tulelake Irrigation District Lateral M-2 Lining

Question and Answers From July 17, 2001 Site Visit

Firestone

1. Explain the function of the lifting bar.

To allow safe and efficient deployment of heavy, large rolls of geomembrane in the field and from the delivery truck.

2. Where is the delivery destination?

The Tulelake Irrigation District compound at 2717 Havlina Road, Tukelake, California.

3. Is there a max roll weight?

Maximum roll weight is 5,000 pounds.

4. Is the bid for 400,000 sq ft or 2.3 miles, 30 ft wide?

The Government will purchase 400,000 ft^2 of the geomembrane material. There have been associated questions about whether panel widths greater or lesser than 30 feet would be allowed, how would they be paid for, is there an allowance for overlaps and seams. The Government's need is to line 12,000 lineal feet of canal with panels having a minimum width of 29.5 feet. The specified quantity (400,000 ft^2) provides an allowance for overlaps, seams, waste, and various contingencies. The Contractor may propose panel widths not less than 29.5 feet and not greater than 32.0 feet but the proposal must demonstrate that their system will meet the width and lineal foot criteria stated above.

5. Is there a bid form?

Use Standard Form 18.

6. Why was this canal picked from all the canals in the area?

The Governor of Oregon has issued a drought declaration for the area. Funds are available for implementing temporary emergency drought relief measures. The Tulelake Irrigation District has proposed lining this reach of Lateral M-2 because it is a known area of high water losses. Ponding tests will be conducted prior to liner installation so that the effectiveness of the liner can be assessed. The Tulelake Irrigation District is contemplating lining additional reaches in the future.

Colorado Lining International

1. Would it be better if the liner was textured or smooth?

The Government will consider either textured or smooth liners.

C.W. Neal Corp.

1. Type of material?

The Government will consider all geomembrane materials that are normally used in the proposed application. The only additional requirement not identified in the original solicitation is that the geomembrane material must be UV resistant.

2. Is it a reinforced material?

The Government will consider either reinforced or non-reinforced geomembrane materials.

3. Color of material?

The Government will consider all material colors.

4. Any deployment preferences - from the center - or side?

The Government has no preferences in this regard. Please address in your proposal any advantages for deployment. Ease of installation is an evaluation factor.

5. 30 ft wide by 200 ft long max - no seam in the middle?

The only field seams that the irrigation district will perform are seams that are transverse to the canal flow and seams that they are qualified to perform.

Seams "in the middle" we define as seams running parallel to the canal flow. The Government will accept seams "in the middle" if the seams are constructed in the factory, or are performed in the field by machines (e.g. hot wedge welder) by and at the expense of the Contractor.

BAFSCO

1. On bid material is stated to be exposed to UV, no specifications that it must be UV resistant?

All geomembrane materials shall be UV resistant.

COLAS

1. Would a more durable material be acceptable instead of a geotextile cushion in the rocky areas?

Possibly. The Contractor's proposal must demonstrate that the proposed geomembrane system can function in an equivalent manner to the specified geomembrane plus geotextile cushion system.

Watersaver

1. Can factory seams run parallel to the length of the canal?

See answer for C.W. Neal Corp question number 5 above.

2. Is a color for the liner specified?

The Government will consider all material colors.

3. Is there a specification for the liner other than 45 mils and UV stable? Shouldn't the liner be reinforced?

All geomembrane materials shall be UV resistant and minimum 45 mils thickness. The Government will consider either reinforced or non-reinforced geomembrane materials.

4. Is there a bid form or can we use our own quotation form?

Use Standard Form 18.

5. Our width increment is +31 ft. Is it okay to use this width?

See answer for C.W. Neal Corp question number 5 above.

Additional information presented at the site visit

1. Batten strips and mechanical anchorage that may be required at certain locations such as turnouts are NOT to be furnished by the contractor. The Contractor's technical expert (CLIN 0006) shall provide technical assistance on the methods and materials for completing these installations.

2. At the road crossings the geomembranes will be set in anchor trenches rather than

mechanically attached to the crossing structures.

3. A 1.5 to 2.0 wide "ledge" will be excavated on the canal sideslope for anchoring the upper edge of the geomembrane. The ledge will be located approximately one foot above the high water line. The excavated soil will then be placed back on top of the geomembrane.

4. There is a road on both sides of the canal which will be used for completing the installation.

Tulelake Irrigation District Canal Lining Project
Technical Evaluation Worksheet

Proposal:_____

TECHNICAL CAPABILITY

The proposal must be technically adequate, proving the material proposed meets the following items: A. ease of installation, B. damage resistance, C. ease of repair, D. expected life, and E. seepage control.

Determine a numerical rating for this proposal using the two definitions below as representing the opposing extremes of the rating scale. Give your rating to the nearest tenth (i.e., 4.1).

A. Ease of Installation 15 Points

(1) Material does not demonstrate ease in handling with normal irrigation district equipment.

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(15) Proposed material clearly shows the ability to be handled by district personnel using their equipment.

Score: _____

Evaluators' Comments:

Tulelake Irrigation District Canal Lining Project
Technical Evaluation Worksheet

Proposal:_____

TECHNICAL CAPABILITY

The proposal must be technically adequate, proving the material proposed meets the following items: A. ease of installation, B. damage resistance, C. ease of repair, D. expected life, and E. seepage control.

Determine a numerical rating for this proposal using the two definitions below as representing the opposing extremes of the rating scale. Give your rating to the nearest tenth (i.e., 4.1).

B. Damage Resistance 5 Points

(1) The material lacks sufficient documentation either through laboratory tests or actual field tests.

(2)

(3)

(4)

(5) Material clearly has demonstrated through lab testing or field testing it's damage resistance.

Score: _____

Evaluators' Comments:

Tulelake Irrigation District Canal Lining Project
Technical Evaluation Worksheet

Proposal:_____

TECHNICAL CAPABILITY

The proposal must be technically adequate, proving the material proposed meets the following items: A. ease of installation, B. damage resistance, C. ease of repair, D. expected life, and E. seepage control.

Determine a numerical rating for this proposal using the two definitions below as representing the opposing extremes of the rating scale. Give your rating to the nearest tenth (i.e., 4.1).

C. Ease of Repair 10 Points

(1) Proposed material lacks documentation showing its ease of being repair by irrigation districts.

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(10) Material has demonstrated its ease of repair through actual documentation of district personnel doing work.

Score: _____

Evaluators' Comments:

Tulelake Irrigation District Canal Lining Project
Technical Evaluation Worksheet

Proposal:_____

TECHNICAL CAPABILITY

The proposal must be technically adequate, proving the material proposed meets the following items: A. ease of installation, B. damage resistance, C. ease of repair, D. expected life, and E. seepage control.

Determine a numerical rating for this proposal using the two definitions below as representing the opposing extremes of the rating scale. Give your rating to the nearest tenth (i.e., 4.1).

D. Expected Life 5 Points

(1) The material lacks documentation to demonstrate a reasonable chance of success.

(2)

(3)

(4)

(5) Proposed material has a complete history and documentation showing its durability capabilities.

Score: _____

Evaluators' Comments:

Tulelake Irrigation District Canal Lining Project
Technical Evaluation Worksheet

Proposal:_____

TECHNICAL CAPABILITY

The proposal must be technically adequate, proving the material proposed meets the following items: A. ease of installation, B. damage resistance, C. ease of repair, D. expected life, and E. seepage control.

Determine a numerical rating for this proposal using the two definitions below as representing the opposing extremes of the rating scale. Give your rating to the nearest tenth (i.e., 4.1).

E. Seepage Control 5 Points

(1) Material proposed has no documentation showing its seepage resistence.

(2)

(3)

(4)

(5) Material proposed has shown it's seepage resistence through fully documented studies or testing.

Score: _____

Evaluators' Comments:

Tulelake Irrigation District Canal Lining Project
Technical Evaluation Worksheet

Proposal:_____

PAST PERFORMANCE 10 Points

Potential material needs to demonstrate it's experience by showing installations which have the same or similar installation procedures and subgrades.

Determine a numerical rating for this proposal using the two definitions below as representing the opposing extremes of the rating scale. Give your rating to the nearest tenth (i.e., 4.1).

(1) The proposed material lacks information documentation regarding its capability to be used in this application. No information on previous installations is presented.

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(10) The material adequately documents its passed performance for this type application. The proposal contains documentation of previous successful installations of its application.

Score: _____

Evaluators' Comments:

Tulelake Irrigation District Canal Lining Project
Summary of Technical Evaluation

Proposal:_____

Technical Capability:

A. Ease of Installation	_____	**out of 15 Points**
B. Damage Resistance	_____	**out of 5 Points**
C. Ease of Repair	_____	**out of 10 Points**
D. Expected Life	_____	**out of 5 Points**
E. Seepage Control	_____	**out of 5 Points**
Past Performance:	_____	**out of 10 Points**
Total Technical Points:	_____	**out of 50 Points**

Tulelake Irrigation District Canal Lining Project
Technical Evaluation - Summary of Proposals

Evaluation Factor	Proposal 1	Proposal 2	Proposal 3	Proposal 4	Proposal 5
Ease of installation					
Damage resistance					
Ease of repair					
Expected life					
Seepage control					
Past performance					
Total Technical Points					

ESTIMATED SEEPAGE LOSSES FOR THE M-2 LATERIAL[1]
(Based on 240 day Irrigation Season)

Tulelake Irrigation District M-2 Laterial Description	Water Depth feet	Side Slope	Bottom width feet	Length feet	Length miles	Constant[2] ft3/ft2 day	Seepage CFD	Seepage AC-FT/D	Seepage AC-FT/Y
Sta. 2+50 to 22+90 Lined Earth									
Current conditions	4.0	1.0	15.0	2,040	0.4	0.40	21,470	0.49	118
All canal lined[1]	4.0	1.5	12.0	2,040	0.4	0.07	3,770	0.09	22
Sta. 22+90 to 23+90 (Between Hwy Br. and RR Br.)									
Current conditions	4.0	1.0	15.0	100	0.0	0.50	1,320	0.03	7
Sta. 23+90 to 27+34 Culvert									
Current conditions	4.0	1.0	15.0	344	0.1	0.50	4,530	0.10	24
All canal lined	4.0	1.5	12.0	344	0.1	0.07	640	0.01	2
Sta. 27+34 to 28+00 Check									
Current conditions	4.0	1.0	15.0	66	0.0	0.50	870	0.02	5
All canal lined	4.0	1.5	12.0	66	0.0	0.07	120	0.00	0
Sta. 28+00 to 74+48									
Current conditions	4.0	1.0	15.0	4,648	0.9	0.65	79,500	1.83	439
All canal lined	4.0	1.5	12.0	4,648	0.9	0.07	8,600	0.20	48
Sta. 74+48 to 121+92									
Current conditions	4.0	1.0	15.0	4,744	0.9	0.80	99,870	2.29	550
All canal lined	4.0	1.5	12.0	4,744	0.9	0.07	8,770	0.20	48
				11,942	2.3		Before Lining		1,143.0
							After Lining		120.0
							Total Savings		1,023.0

[1] The M-2 Laterial was lined with Firestone Building Products Co. - 45-mil EPDM RubberGard on Oct. 3-21, 2001.
[2] A seepage constant of 0.07 (new concrete) was used which would allow for some seepage around structures.