R-97-01

DESCHUTES—CANAL-LINING DEMONSTRATION PROJECT

YEAR 5 DURABILITY REPORT

Upper Deschutes River Basin Water Conservation Program

January 1997

U.S. DEPARTMENT OF THE INTERIOR
Bureau of Reclamation

Pacific Northwest Region
Water Conservation Center

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The Deschutes Canal-Lining Demonstration Project is a cooperative effort among the Bureau of Reclamation, Deschutes River Basin irrigation districts in central Oregon, the Lugert-Altus Irrigation District in Oklahoma, and several geosynthetic lining manufacturers. The purpose of this study is to develop low-cost canal-lining technologies to reduce seepage over severe rocky subgrade conditions. The 22 test sections include combinations of geosynthetics, soil, concrete grout, shotcrete, elastomeric coatings, and sprayed-in-place foam. This report assesses the performance of the original 18 test sections after 5 years of service. This report also documents the construction of four additional test sections and assesses their performance after about 2 years of service.

At this time, 7 of the 22 test sections have failed, while the remaining 15 test sections are in very good to excellent condition. Each test section covers about 30,000 square feet, and unit construction costs ranged from $1.22 to $4.33 per square foot. Pre- and post-construction ponding tests have generally shown that the concrete liners stop about 90 percent of the seepage in the short-term, while the geomembrane liners stop about 99 percent of the seepage. Additional ponding tests are planned for next year to determine seepage rates after 5 to 6 years of service.

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DESCHUTES—CANAL-LINING DEMONSTRATION PROJECT
YEAR 5 DURABILITY REPORT

by

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Technical Service Center
Denver, Colorado

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Pacific Northwest Region
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UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION

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The authors wish to thank the irrigation community in central Oregon, whose support was essential to the planning and implementation of the demonstration project. Reclamation particularly appreciates the support from the boards of directors of the Arnold, North Unit, and Tumalo Irrigation Districts. Water user support consisted of both a financial commitment and the acceptance of the risks involved with using unfamiliar technologies.

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

Finally, the authors wish to recognize the contribution made by Ms. Teresa Provine of Reclamation's Oklahoma-Texas Area Office and the board of directors of the Lugert-Altus Irrigation District who collaborated to line a ½-mile section of canal with an exposed bituminous geomembrane and who have agreed to include that ½-mile section in this study.

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Mission Statement

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally-owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

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GLOSSARY

CSPE	=	Chlorosulfanated polyethylene
CSPE-R	=	Reinforced chlorosulfanated polyethylene
HDPE	=	High density polyethylene
LAID	=	Lugert-Altus Irrigation District
PVC	=	Polyvinyl chloride
UDRBWCP	=	Upper Deschutes River Basin Water Conservation Project
UV	=	Ultraviolet
VLDPE	=	Very low density polyethylene

SUMMARY

The U.S. Bureau of Reclamation has constructed 22 canal-lining test sections to assess their durability and effectiveness (seepage reduction) over severe rocky subgrade conditions. Twenty-one test sections were constructed in central Oregon, and the newest test section was constructed in Oklahoma. The lining materials include combinations of geosynthetics, concrete grout, shotcrete, elastomeric coatings, and sprayed-in-place foam. The test sections now range in age from 1½ to 5 years. Reclamation has visually inspected the test sections every 6 to 12 months. The inspections are typically performed either in October when the water is shut off at the end of the irrigation season, or in March after maintenance is completed but before the water is turned on for the new irrigation season. The irrigation districts have carefully documented their maintenance costs.

After up to 5 years of service, differences in the performance of the 22 test sections are becoming obvious. The two exposed coated-geotextile test sections washed out completely the first year; the Liquid Boot on the invert of the concrete flume washed out the first year; the two sprayed-in-place polyurethane foam test sections washed out and need extensive repairs; and the two test sections with grout-filled mattresses on the side slopes only were abondoned when the exposed invert membranes were removed because of uplift problems. The remaining 15 test sections are all in very good to excellent condition.

CHAPTER I
INTRODUCTION

This report is the third in a series of reports describing the Deschutes Canal Lining Demonstration Project. To date, 22 test sections have been constructed on four irrigation districts (three irrigation districts in the Bend, Oregon area and one in the Altus, Oklahoma area). The lining materials include combinations of geosynthetics, concrete grout, shotcrete, elastomeric coatings, and sprayed-in-place foam. The test sections are being evaluated for durability and effectiveness in reducing seepage.

The first report, *Deschutes - Construction Report*,[1] documented the construction of the original 18 test sections on the Arnold and North Unit Irrigation Districts near Bend, Oregon. These 18 test sections were constructed over severe rocky subgrade conditions. The construction report detailed construction techniques, construction materials, unit construction costs, and ponding tests to determine seepage rates both before and after construction of the test sections. Post-construction seepage rates were 10 to 100 times lower than pre-construction rates. Unit construction costs for the original 18 test sections are included in table 1.

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

This third report details the construction of 4 additional test sections. Unit construction costs for the 4 new test sections are included in table 2. This report also assesses the condition of all 22 test sections after up to 5 years of service (through October 1996). Beginning with this report, the scope of this study has expanded beyond the Deschutes River Basin. The U.S. Bureau of Reclamation's (Reclamation) Oklahoma City office and the Lugert-Altus Irrigation District (located in Altus, Oklahoma) are new collaborators on this study and have constructed a test section using an elastomeric bitumen geomembrane (tradename Teranap, supplied by Siplast Inc.).

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

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[1] Reclamation Report R-94-06, 1994
[2] Reclamation Report R-94-14, 1994

Table 1.—Canal Lining Costs - Arnold and North Unit Test Sections

Section No.	Arnold Irrigation District Description	Lining Material: Geomembrane Cost per sq. foot $	Lining Material: Geotextile Cost per sq. foot $	Lining Material: Shotcrete Cost per sq. foot $	Lining Material: Other Cost per sq. foot $	Subgrade Preparation Cost per sq.foot $	Installation Cost per sq. foot $	Contingencies, Overhead and Profit %	Total* $
A-1	Petromat MB II with 3-in. Shotcrete cover								
	Unreinforced Shotcrete	$0.30		$0.65		$0.26	$0.55	17%	$2.06
	1-1/2 lbs. per cubic yard	$0.30		$0.65	$0.05	$0.26	$0.55	17%	$2.12
A-2	30-mil VLDPE textured geomembrane with 3-in. unreinforced Shotcrete cover and 16-oz geotextile cushion	$0.25	$0.12	$0.65		$0.26	$0.55	17%	$2.14
A-3	80-mil HDPE textured geomembrane	$0.70	$0.12			$0.26	$0.10	17%	$1.38
A-4	Geolam with 6-oz. geotextile cushion	$0.45	$0.07			$0.26	$0.12	17%	$1.05
A-5	45-mil Hypalon with 16-oz. geotextile cushion	$0.45	$0.12			$0.26	$0.12	17%	$1.11
A-6	TerraTuff (36-mil Hypalon/8-oz. geotextile)	$0.50				$0.26	$0.12	17%	$1.03
A-7	40-mil PVC with 3-in. Grout-Filled Mattress	$0.35		$0.65	$0.45	$0.12	$0.45	17%	$2.36
A-8	3-in. Unreinforced Grout-Filled Mattress			$0.65	$0.45	$0.04	$0.45	17%	$1.86
A-9 & A-10	60-mil VLDPE or HDPE with 12-oz. geotextile cushion and 3-in. Grout-Filled Mattress on side slopes only* *	$0.55	$0.12	$0.21	$0.16	$0.04	$0.45	17%	$1.79
Section No.	**North Unit Irrigation District Description**	0.							
N-1	Spray-applied Polyurethane Foam base with Urethane 500/550 protective coating				$2.41	$0.04	$1.25`	17%	$4.33
N-2	Spray-applied Polyurethane Foam base 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-6	3-in. Steel-Fiber Reinforced Shotcrete								
	50 lbs. per cubic yard			$0.65	$0.22	$0.04	$0.45	17%	$1.59
	25 lbs. per cubic yard			$0.65	$0.09	$0.04	$0.45	17%	$1.44
N-7 & N-8	3-in Polyfiber Reinforced Shotcrete								
	3 lbs. per cubic yard			$0.65	$0.12	$0.04	$0.45	17%	$1.47
	1-1/2 lbs. per cubic yard			$0.65	$0.05	$0.04	$0.45	17%	$1.39
N-9	3-in. Unreinforced Shotcrete			$0.65		$0.04	$0.45	17%	$1.33

* These costs are based on 1992 dollars.

**This cost is based on a 30-foot- wide sheet of geomembrane with 5-foot-wide grout-filled mattress on each side slope used as an anchor.

Table 2.—Canal Lining Costs - Tumalo Test Sections

Section No.	Tumalo Irrigation District Description	Lining Material Geomembrane Cost per sq. foot $	Geotextile Cost per sq. foot $	Shotcrete Cost per sq. foot $	Other Cost per sq. foot $	Subgrade Preparation Cost per sq.foot $	Installation Cost per sq. foot $	Contingencies, Overhead, and Profit %	Total* $
T-1	100-mil Liquid Boot over an existing concrete flume				$1.20	$0.15	$0.10	17%	$1.70
T-2	80-mil Liquid Boot over a sandblasted steel flume				$1.00	$0.75	$0.10	17%	$2.16
T-3	80-mil Liquid Boot over a broomed steel flume				$1.00	$0.10	$0.10	17%	$1.40

* These costs are based on 1994 dollars.

Table 3.—Canal Lining Costs - Lugert-Altus Test Sections

Section No.	Lugert-Altus Irrigation District Description		Lining Material Geomembrane Cost per sq. foot $	Geotextile Cost per sq. foot $	Shotcrete Cost per sq. foot $	Other Cost per sq. foot $	Subgrade Preparation Cost per sq.foot $	Installation Cost per sq. foot $	Contingencies, Overhead, and Profit %	Total* $
L-1	Exposed Teranap	120 mil	0.80				0.12	0.12	17%	1.22
		160 mil	0.95				0.12	0.12	17%	1.39

* These costs are based on 1994 dollars.

CHAPTER II
NEW TEST SECTIONS

Tumalo Irrigation District

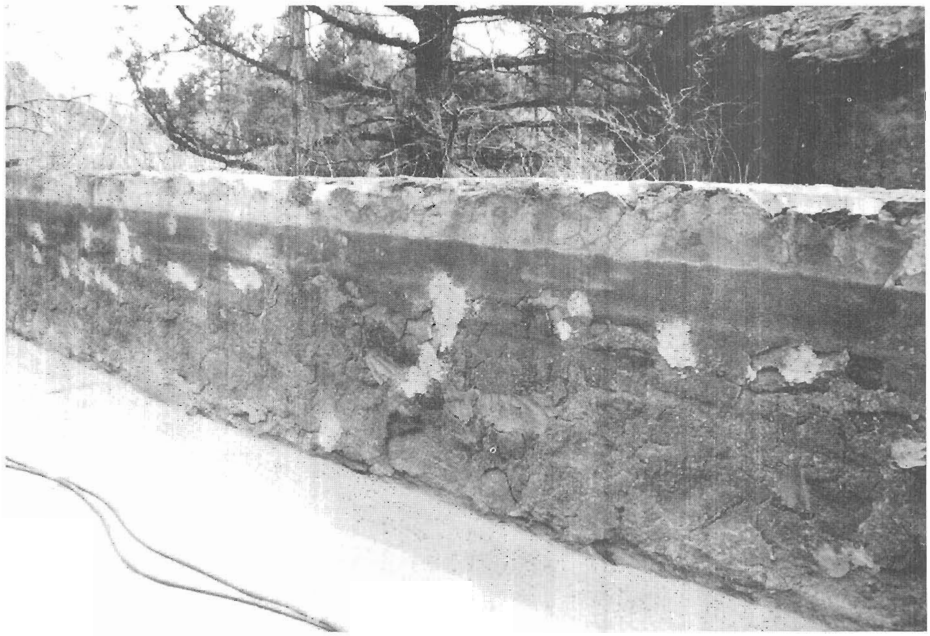
Background.—Tumalo Irrigation District is located on the west side of the Deschutes River, 5 miles northwest of the city of Bend, in central Oregon. The district provides irrigation water for about 8,000 acres of irrigable land. The main project features include 26 miles of unlined canal, 60 miles of unlined laterals, 4 flumes totaling about 2,000 feet, 3 miles of pipeline, and a 750-foot tunnel. The water supply comes from the natural flows of Tumalo Creek and the Deschutes River and storage in Cresent Lake. The Bend Feed Canal diverts water from the Deschutes River. The design capacity of the canal was 240 cubic feet per second (cfs); however, subsequent system modifications have reduced the maximum capacity to 165 cfs. The Tumalo Feed Canal delivers water from Tumalo Creek and has a maximum capacity of 80 cfs.

Test Sections.—Tumalo Irrigation District has rehabilitated three leaky flumes using spray applied Liquid Boot (80- to 100-mils thick). A data sheet for the Liquid Boot is included in appendix A. The work was performed by Tumalo Irrigation District personnel with assistance from the Liquid Boot manufacturer. The first test section (T-1) is the concrete flume immediately downstream from the diversion dam on the Deschutes River. The other two test sections (T-2 and T-3) are elevated steel flumes that carry water across small valleys.

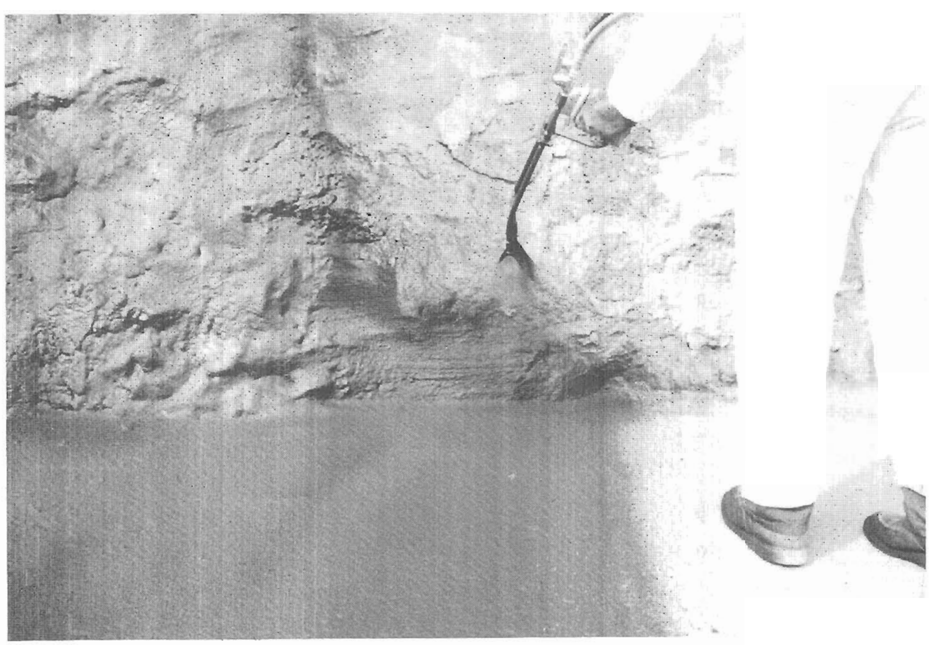
Test Section T-1.—

Material:	Liquid Boot over an existing concrete flume
Date Installed:	April 1994
Location:	Bend Feed Canal Headworks (75 linear feet; 1,575 square feet)
Description:	Liquid Boot is a neoprene-polymer-modified asphalt emulsion which is spray-applied at ambient temperature to form a self-bonding monolithic rubber-like membrane. The two components (8:1 mix ratio) are spray-applied simultaneously. The catalyst ("B" component) causes the emulsion ("A" component) to set instantly as it hits the surface. Liquid Boot is non-toxic and non-hazardous and can withstand over 1,000 percent elongation with 90 percent recovery.
Prime Contractor:	Tumalo Irrigation District
Material Supplier:	LBI Technologies, Inc.
Subgrade Prep:	The existing concrete-lined canal was broom-cleaned and blasted with compressed air. Large voids in the stone and concrete side walls were patched with cement grout. A cut-off trench was not used on this test section.
Construction:	The main purpose of this test section was to train the irrigation district personnel. Following a 3-hour training session provided by LBI Technologies Inc. (LBI), Tumalo Irrigation District personnel spray-applied the membrane to the concrete flume (11-foot horizontal invert with 5-foot vertical side walls). The Liquid Boot was applied in a single thick coat to an average thickness of 80 mils on the relatively smooth invert. Extra material was sprayed on the side walls (average thickness estimated at 100 to 120 mils) to obtain satisfactory coverage over the irregular surface. The irrigation district personnel had no trouble learning the application process. The use of a geotextile embedded in the Liquid Boot was considered but abandoned at the recommendation of LBI.
Difficulties:	The irregular stone and cement side walls required additional Liquid Boot to achieve the desired minimum thickness (about 60 mils).
Unit Cost Estimate:	Liquid Boot (100 mils average) spray-applied over concrete flume: $1.70 per square foot
Photographs:	1 through 4

Tumalo Irrigation District - Test Section T-1
Liquid Boot over an existing concrete flume

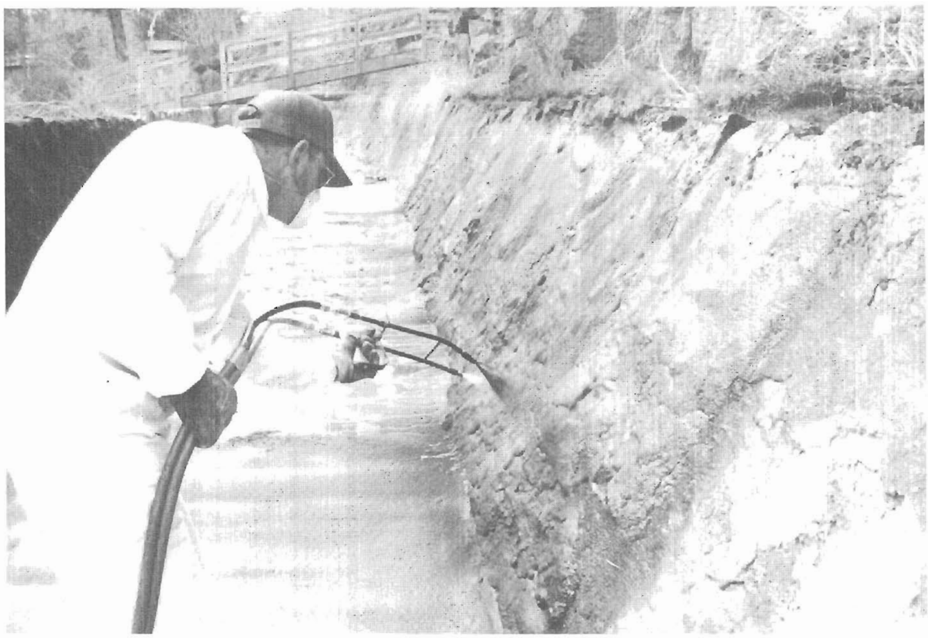


Photograph 1.—Cement grout was used to patch large voids in the stone and cement side walls.



Photograph 2 .— Liquid Boot was applied in a single pass. The invert and side walls were coated concurrently.

Tumalo Irrigation District - Test Section T-1
Liquid Boot over an existing concrete flume



Photograph 3 .— Irrigation district personnel applying the two-part Liquid Boot.

Photograph 4 .— Finished Liquid Boot installation. Note the water released from the Liquid Boot emulsion collecting in the invert.

Test Section T-2.—

Material:	Liquid Boot over a sandblasted steel flume
Date Installed:	April 1994
Location:	Flume #4 - Bend Feed Canal (463 linear feet; 7,871 square feet)
Description:	Liquid Boot is a neoprene-polymer-modified asphalt emulsion which is spray-applied at ambient temperature to form a self-bonding monolithic rubber-like membrane. The two components (8:1 mix ratio) are spray-applied simultaneously. The catalyst ("B" component) causes the emulsion ("A" component) to set instantly as it hits the surface. Liquid Boot is non-toxic and non-hazardous and can withstand over 1,000 percent elongation with 90 percent recovery.
Prime Contractor:	Tumalo Irrigation District
Material Supplier:	LBI Technologies, Inc.
Subgrade Prep:	The semi-circular steel flume (17-foot perimeter) was sandblasted (brush blast) to remove rust scale and dirt and then broomed to remove sand and debris. Pin holes in the steel were not patched, and no extra effort was made to remove prior applications of tar from the joints. A cut-off trench was saw-cut into the concrete transition at the upstream edge of the flume.
Construction:	Under the supervision of LBI Technologies, Tumalo Irrigation District personnel spray-applied the membrane to the entire inside face of the steel flume in a single thick coat to an average thickness of 80 mils (minimum thickness estimated at 60 mils). The district personnel started at the flume midpoint and worked their way out. They then moved their equipment around to the other end of the flume, and again they worked from the middle out. Joints were coated with particular care to insure a continuous membrane over previous applications of mastic joint patch. A geotextile layer was placed into a tack coat of fresh Liquid Boot around the corners in the flume clean-out drain. Additional Liquid Boot was then applied over the geotextile. The next day, the Liquid Boot membrane was inspected for holidays and blisters, which were repaired with Liquid Boot Trowel Grade.
Difficulties:	After the surface preparation was completed, rain prevented application of the Liquid Boot for 7 days. When the rain stopped, a blow torch was rented to dry the bottom of the flume before application of the Liquid Boot. Some new rust scale had developed by this time.

Water is released from the Liquid Boot emulsion when it reacts with the catalyst. This water collected in the invert, retarding cure in that location. When inspected the next day, the water was gone, but several blisters had developed which had to be lanced and patched with Liquid Boot Trowel Grade.

Unit Cost Estimate: Liquid Boot (80 mils average) spray-applied over a steel flume: $2.16 per square foot

Advantages: The Liquid Boot lining system is fast and easy to apply. With a moderate investment in pump equipment ($6,000 purchase or $200 per day rental), irrigation districts can apply it themselves, saving money and allowing flexibility in construction schedules to accommodate bad weather and fluctuating workload. The bond to sandblasted steel appears to be very good. The high elasticity of the membrane should be well suited to withstand thermal expansion and contraction. Being a polymer emulsion, Liquid Boot should be less affected by damp subgrade conditions than other spray-applied membranes. The District is equipped to make minor repairs with the Liquid Boot Trowel Grade.

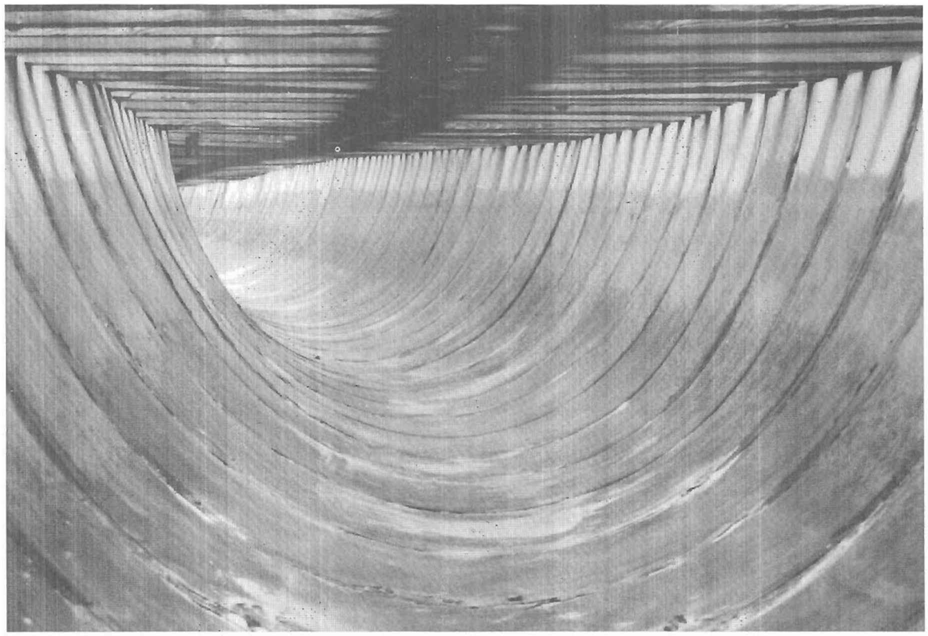
Disadvantages: Surface preparation is critical for the bond of any spray-applied membrane. Long-term bond to the sandblasted steel flume is unproven at this time. Sandblasting was a major cost for this test section, and elimination of sandblasting was discussed for an additional test section.

Because irrigation canals are in use during prime construction seasons (April through September), construction must be completed during the winter months or during very short construction windows in late fall or early spring. The Liquid Boot membrane is fabricated on-site and is therefore susceptible to adverse weather conditions, such as cold temperatures, wind, snow, and rain. Minimum application temperature is 45°F.

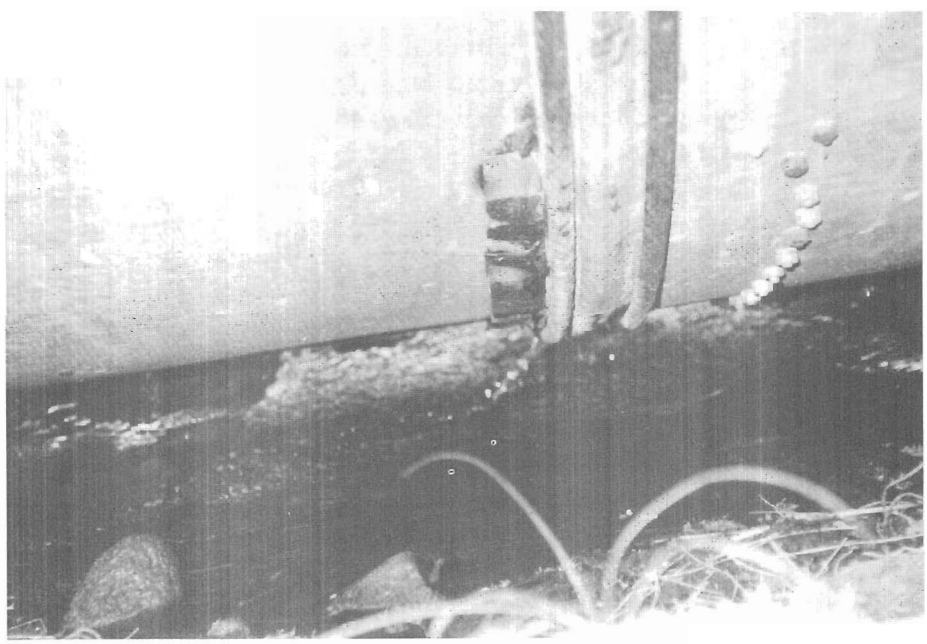
Exposed membranes are susceptible to weathering (especially from ultraviolet light), animal damage, and vandalism.

Photographs: 5 through 15

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

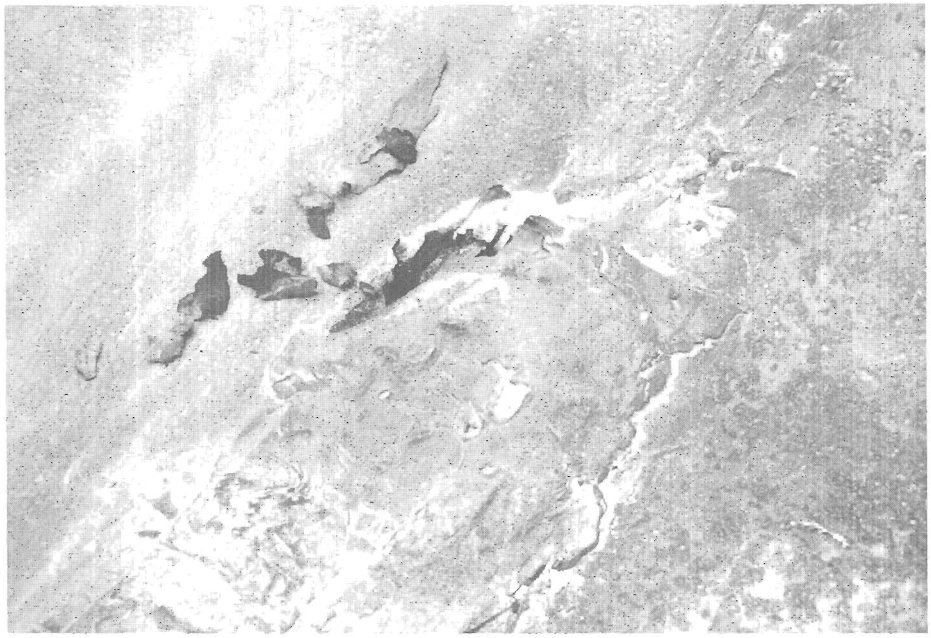


Photograph 5.—Flume #4 after sandblasting and brooming.

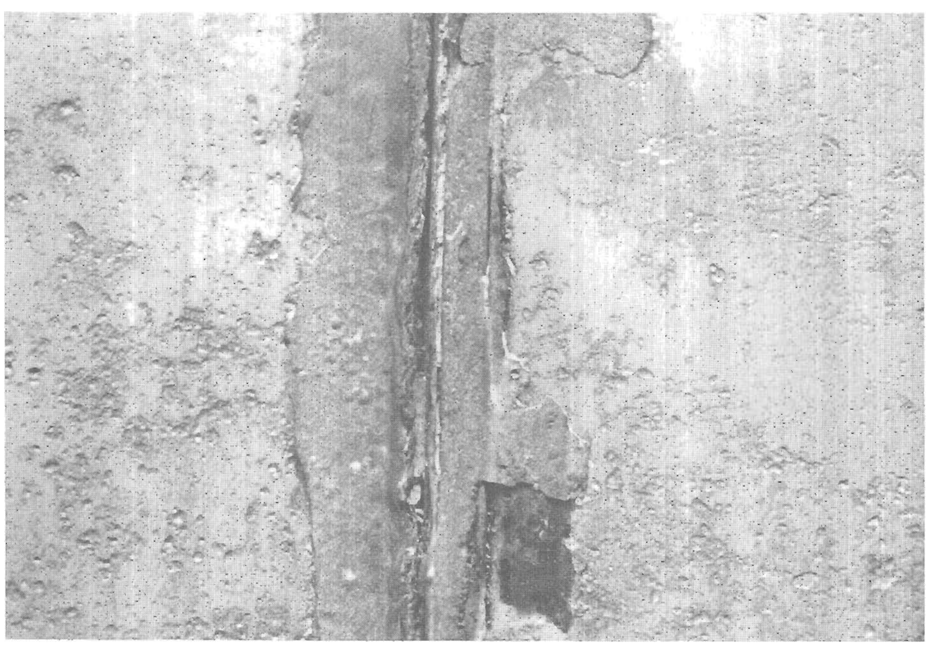


Photograph 6.—Typical seepage between steel panels.

Liquid Boot over a sandblasted steel flume



Photograph 7.—Sandblasting did not remove the tar-based joint patch that was previously used to seal the seams between steel panels.



Photograph 8.—Another joint after sandblasting with tar-based joint sealant still intact.

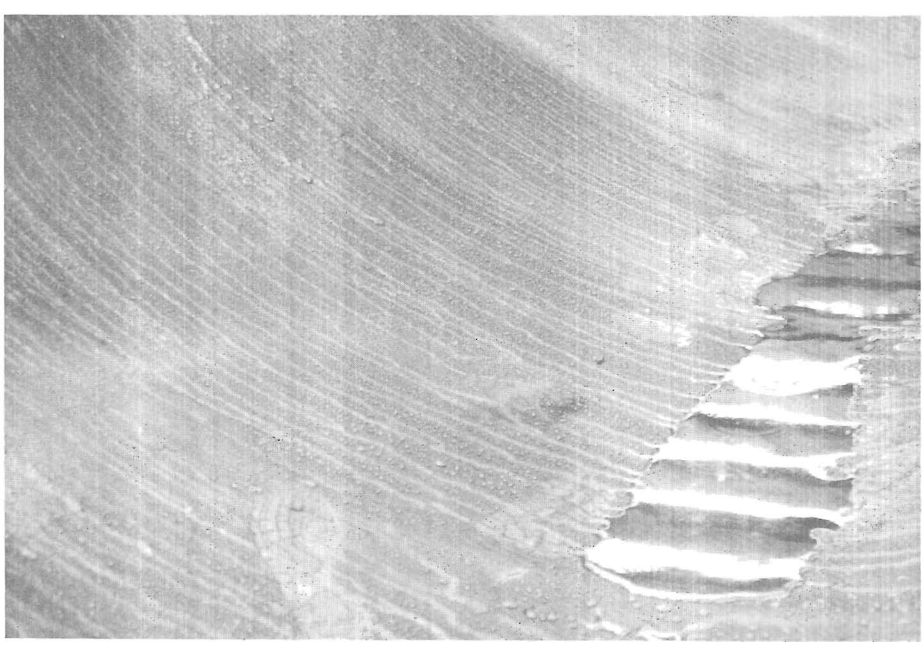
Tumalo Irrigation District - Test Section T-2
Liquid Boot over a sandblasted steel flume

Photograph 9.—Irrigation district personnel use a propane torch to dry any water in the invert.

Photograph 10.—Liquid Boot is delivered to the jobsite in 55-gallon drums. Dark blue drums are the "A" component, light blue drums are the "B" component.

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

Photograph 11.—Representative from LBI Technologies trains Irrigation District personnel.



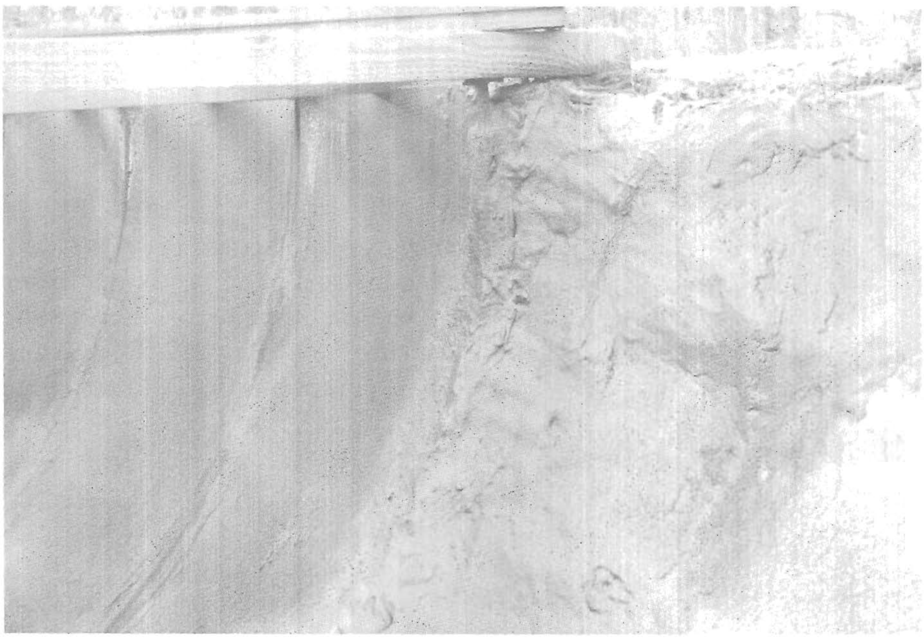
Photograph 12.—Water released from the Liquid Boot emulsion runs down the flume and collects in the invert.

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

Photograph 13.—Trowel-grade Liquid Boot is mixed by hand and used to make small repairs.

Photograph 14.—Typical repair with Liquid Boot trowel-grade.

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



Photograph 15.—Liquid Boot covers the upstream and downstream transitions from shotcrete to steel.

Test Section T-3.—

Material:	Liquid Boot over a broomed steel flume
Date Installed:	April 1995
Location:	Klippel Flume - Bend and Tumalo Feed Canals (267 linear feet; 4,539 square feet)
Description:	Liquid Boot is a neoprene-polymer-modified asphalt emulsion which is spray-applied at ambient temperature to form a self-bonding monolithic rubber-like membrane. The two components (8:1 mix ratio) are spray-applied simultaneously. The catalyst ("B" component) causes the emulsion ("A" component) to set instantly as it hits the surface. Liquid Boot is non-toxic, non-hazardous, and reportedly can withstand over 1,000 percent elongation with 90 percent recovery.
Prime Contractor:	Tumalo Irrigation District
Material Supplier:	LBI Technologies, Inc.
Subgrade Prep:	The semi-circular steel flume (17 foot perimeter) was broomed (swept) to remove dirt, then air blasted twice to remove loose rust scale, dust, and debris. Pin holes in the steel were not patched, and no extra effort was made to remove prior applications of tar mastic from the joints.
Construction:	Tumalo Irrigation District personnel spray-applied the membrane to the entire inside surface of the steel flume in a single thick coat to an average thickness of 80 mils (minimum thickness estimated at 60 mils). Joints were coated with particular care to insure a continuous membrane over previous applications of tar joint patch. The next day, the Liquid Boot membrane was inspected for holidays and blisters, which were patched with Liquid Boot Trowel Grade.
Difficulties:	Water is released from the Liquid Boot emulsion when it reacts with the catalyst. This water collected in the invert, retarding cure in that location. When inspected the next day, the water was gone, but several blisters had developed which had to be lanced, drained, and patched with Liquid Boot Trowel Grade.
Unit Cost Estimate:	Liquid Boot (80 mils average) spray-applied over a steel flume - $1.40 per square foot
Advantages:	The Liquid Boot lining system is fast and easy to apply. With a moderate investment in pump equipment ($6,000 purchase or $200 per day rental), irrigation districts can apply it themselves, saving money and allowing flexibility in construction schedules to accommodate bad weather and fluctuating workload. The bond to a broomed steel surface appears to be good. The high elasticity of the membrane

should be well suited to withstand thermal expansion and contraction. Being a polymer emulsion, Liquid Boot should be less affected by damp subgrade conditions than other spray-applied membranes. The District is equipped to make minor repairs with the Liquid Boot trowel grade.

Disadvantages: Surface preparation is critical for the bond of any spray-applied membrane. Elimination of sandblasting was a major cost savings for this test section; however, long-term bond to a steel surface without sandblasting is unproven at this time.

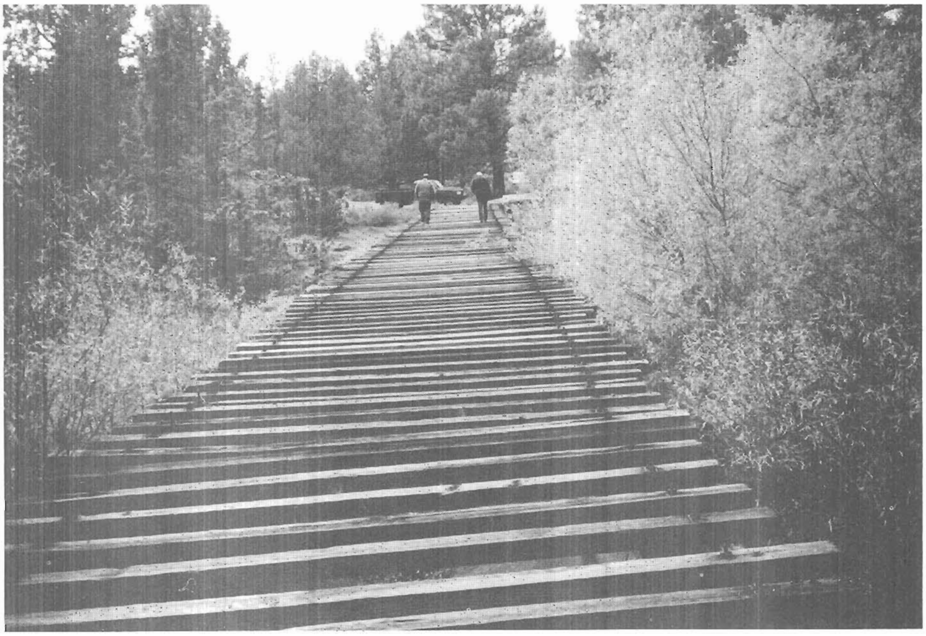
Because irrigation canals are in use during prime construction seasons (April through September), construction must be completed during the winter months or during very short construction windows in late fall or early spring. The Liquid Boot membrane is fabricated on-site, and is therefore susceptible to adverse weather conditions, such as cold temperatures, wind, snow, and rain. Minimum application temperature is 45°F.

Exposed membranes are susceptible to weathering (especially UV light), animal damage, and vandalism.

Photographs: 16 through 17

Tumalo Irrigation District - Test Section T-3
Liquid Boot over a broomed steel flume

Photograph 16.—Side view of flume.



Photograph 17.—Top view of flume.

W.C. Austin Project, Oklahoma

The W.C. Austin Project provides irrigation water for approximately 48,000 acres of privately owned and maintained land in southwestern Oklahoma. Primary crops include cotton, wheat, alfalfa, grain sorghum, and other specialty crops. Eight irrigation districts manage and operate the system, including about 270 miles of unlined gravity-flow canals and laterals. Seepage losses have long been recognized as a problem. Previous investigations have been conducted to identify seepage areas, indicate the cause of the seepage, and recommend remedial actions to rectify the problem. Water losses at the 152 identified seepage areas have adversely affected in excess of 620 acres of arable land. Total water loss due to seepage is estimated at 1,640 acre-feet per irrigation season. Conventional lining methods are very expensive due to the excessive length of canals in need of renovation. Alternative methods are needed that are as effective as conventional lining, but far more cost effective.

Reclamation's Oklahoma-Texas (O-T) Area Office has been working with local irrigation districts to conserve water by lining canals using geomembranes. In 1994, the O-T Area Office and the Lugert-Altus Irrigation District (LAID) collaborated to install a geomembrane lining on a ½-mile stretch of leaking canal near Altus, Oklahoma. The O-T Area Office provided $42,000 to purchase the bulk of the lining, while the LAID provided $15,000 and all the labor and equipment to install the lining. The lining manufacturer provided on-site technical support during installation and a 10-year warranty. This cost-sharing approach is similar to the Deschutes Canal-Lining Demonstration Project; therefore, permission was requested and granted to include the Lugert-Altus installation in the Deschutes Study.

Lugert-Altus Irrigation District

The primary storage reservoir for LAID is Lake Altus, which is formed by W. C. Austin Dam, on the North Fork of the Red River about 18 miles north of Altus Oklahoma. The Main Canal transports water from Lake Altus to the northern boundary of the project's irrigable land. The North Fork of the Red River is crossed about midway along the length of the Main Canal by means of a concrete siphon. The city of Altus also receives municipal and industrial water from the project.

A ½-mile section of the West Canal (a lateral off the Main Canal) was chosen for the test section because of the high seepage which was flooding adjacent productive arable land (location map shown in figure 1). The environmental analysis performed by the O-T Area Office showed no adverse impact on wetland habitat, which has become a factor at many seepage sites surrounding LAID canals. The test section is being monitored for (1) suitability to conditions, (2) constructability, (3) effectiveness in preventing seepage, (4) durability, (5) benefits derived as compared to construction costs, and (6) operation, maintenance, and replacement costs. LAID and Reclamation will visit the site frequently over the next several years to document the overall performance and cost effectiveness of the lining.

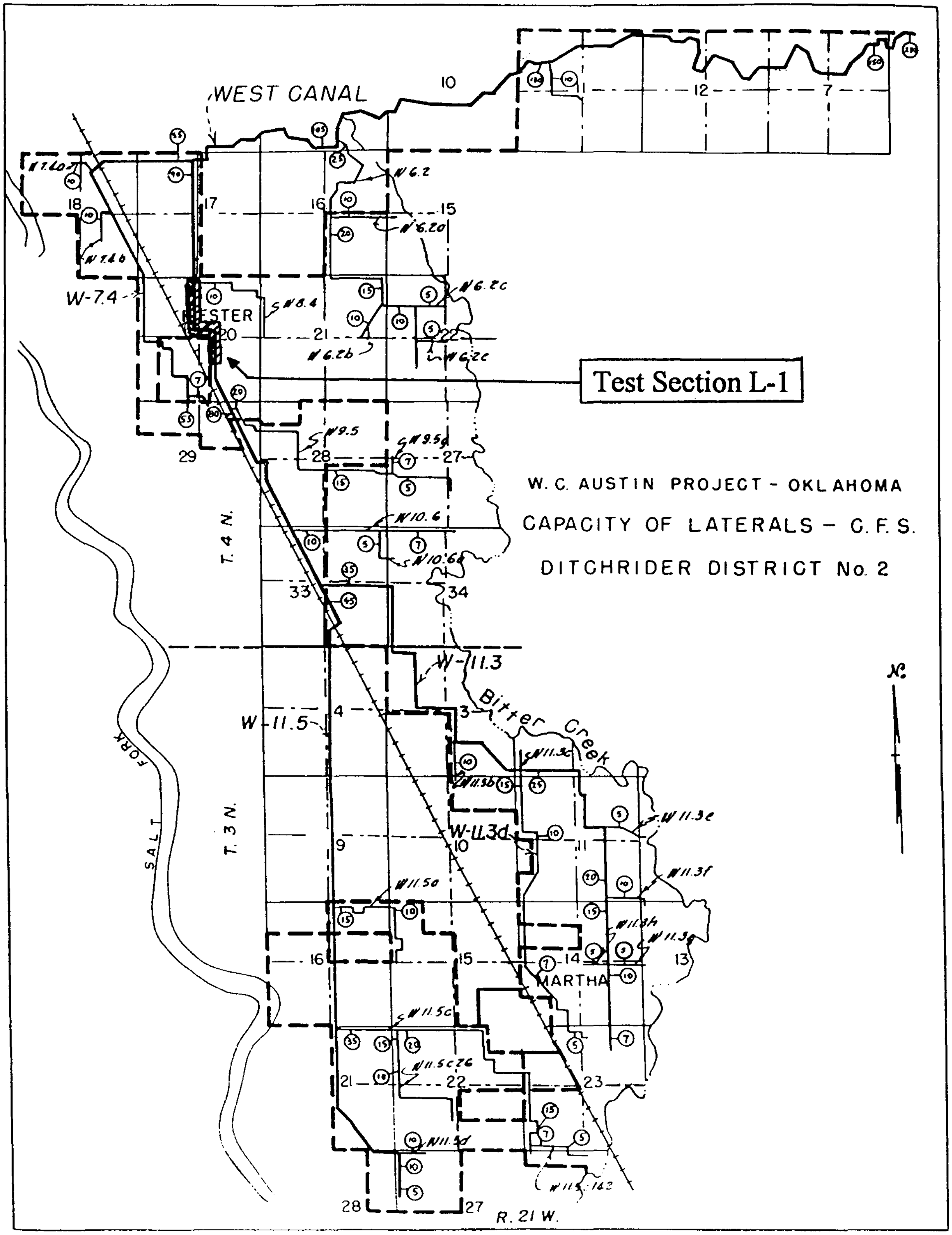


Figure 1.—Location map for Test Section L-1.

Test Section L-1.—

Material:	Exposed Teranap
Date Installed:	May 1994
Location:	West Canal - Lugert-Altus Irrigation District (2,400 linear feet; 70,000 square feet)
Description:	Teranap is an elastomeric bitumen geomembrane, combining Styrene-Butadiene-Styrene (SBS) polymer and asphalt with a polyester reinforcement. Teranap is available in 120-mil and 160-mil thicknesses. A data sheet for Teranap is included in appendix B.
Prime Contractor:	Lugert-Altus Irrigation District (LAID)
Material Supplier:	Siplast, Inc. (France)
Subgrade Prep:	LAID personnel performed moderate subgrade preparation by spraying weeds with herbicide, and then using a backhoe to remove the dead vegetation and all rocks over 1½ inches in diameter. LAID also excavated a small anchor berm on the top of each sideslope.
Construction:	The rolls of Teranap were supported by a backhoe bucket attachment. The Teranap was pulled off the rolls and into place with a truck, using a snatch block attached to the bumper of a second truck (see photos). The Teranap was installed across the canal to an average width of 28 to 29 feet and buried under a 1-foot anchor berm at the top of each bank. (Typical canal cross section shown in figure 2.) Adjacent sheets were overlapped 6 inches, shingled downstream, and seamed with a hot torch. LAID personnel attached the Teranap to existing concrete structures at both the upstream and downstream ends of the 2,400 foot reach. At the downstream end, the Teranap was attached to an existing concrete check structure. The concrete was sandblasted and then primed with roofing asphalt before attachment of the Teranap with the hot torch. At the upstream end, the Teranap was buried in a 1-foot by 1-foot cut-off trench and then attached to an existing concrete siphon. The Teranap was similarly attached to the downstream check structure. In addition, the Teranap was secured to the concrete siphon with a steel batten strip, which was covered with an additional layer of hot-torch-applied Teranap.
Difficulties:	The initial order (62,000 square feet) of 160-mil Teranap was supplied in 13-foot-wide rolls to minimize seaming. This first order proved insufficient, and a second order (8,000 square feet) was needed to complete the installation. The second order was supplied in

6½-foot-wide rolls and contained both 160-mil and 120-mil material. Therefore, the first 2,100 linear feet of canal (starting at the downstream check structure) were lined with 13-foot-wide rolls of 160-mil Teranap. The next 200 feet were lined with 6½-foot-wide rolls of 160-mil Teranap, and the final 100 feet were lined with 6½-foot-wide rolls of 120-mil Teranap.

The irrigation district reported that the Teranap became quite hot and difficult to work with in the summer sun.

Unit Cost Estimate: 160-mil exposed Teranap = $ 1.39 per square foot
120-mil exposed Teranap = $ 1.22 per square foot

Advantages: The Teranap is quite tough and resists damage in this exposed application. The manufacturer is providing a 10-year warranty whereby any wear or damage will be repaired or replaced free of charge. Siplast will inspect and repair annually for the first 4 years, and then every other year through year 10.

Disadvantages: Exposed membranes are susceptible to weathering (especially UV light), animal damage, and vandalism. The 120-mil 331 is not available in 13-foot-wide rolls, thereby requiring additional field seaming.

Photographs: 18 through 23

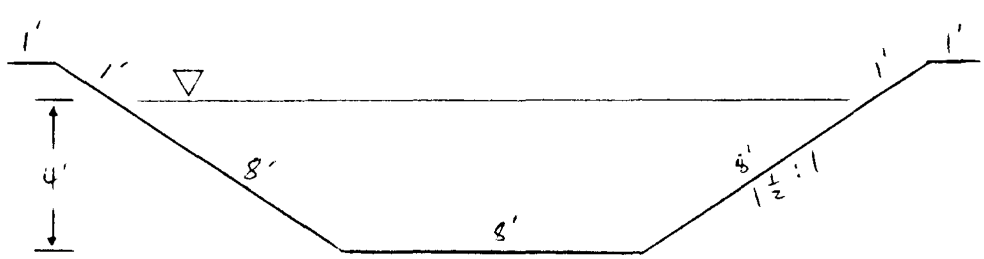
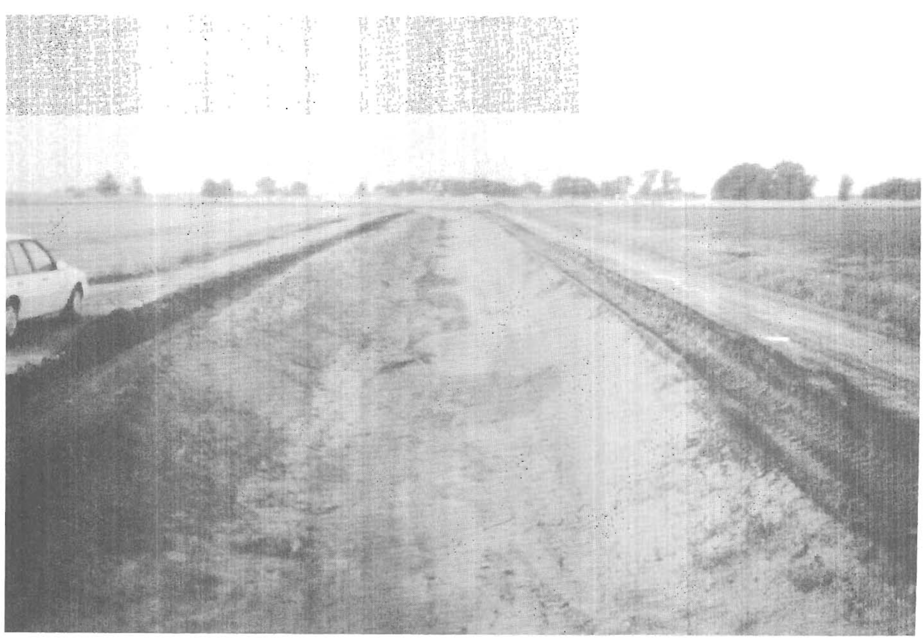


Figure 2.—Typical Canal Cross Section. Maximum depth of water is about 4 feet.

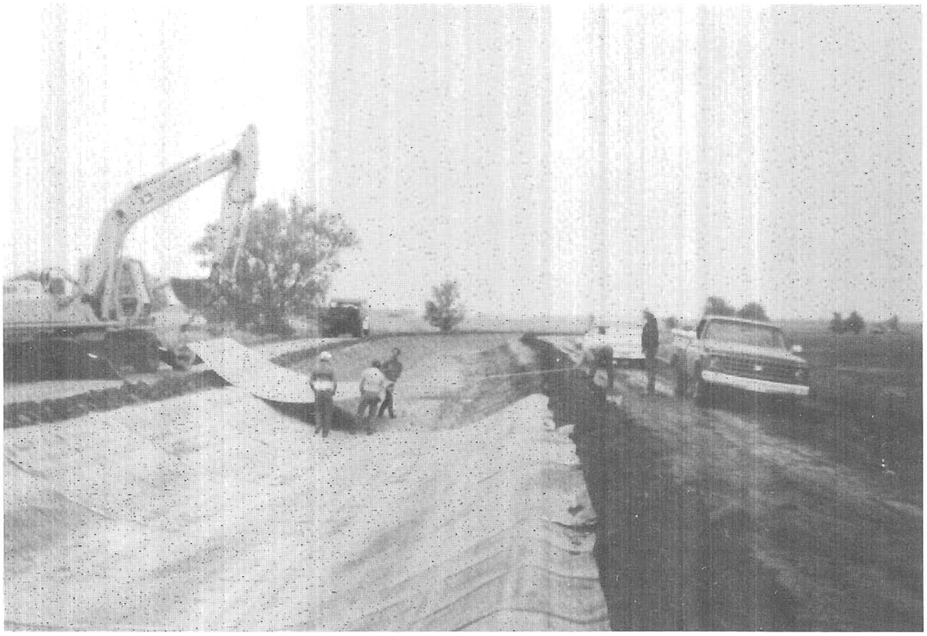
Lugert-Altus Irrigation District - Test Section L-1
Exposed Teranap

Photograph 18.—Pre-existing subgrade conditions - irrigation district sprayed weeds with herbicide, removed the dead vegetation, removed all rocks over 1½" diameter, and reshaped the canal prism.

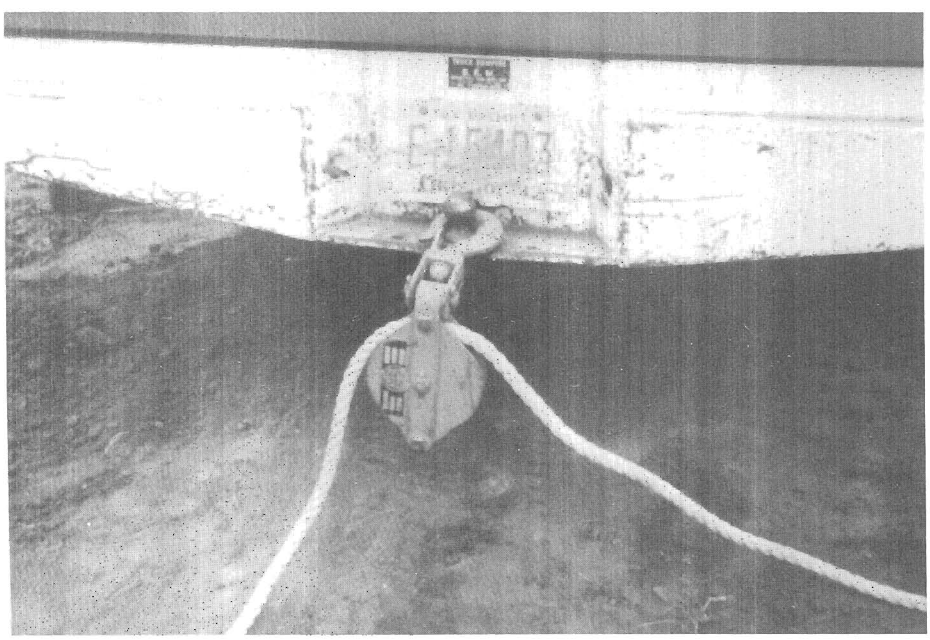


Photograph 19.—Completed subgrade preparation.

Lugert-Altus Irrigation District - Test Section L-1
Exposed Teranap



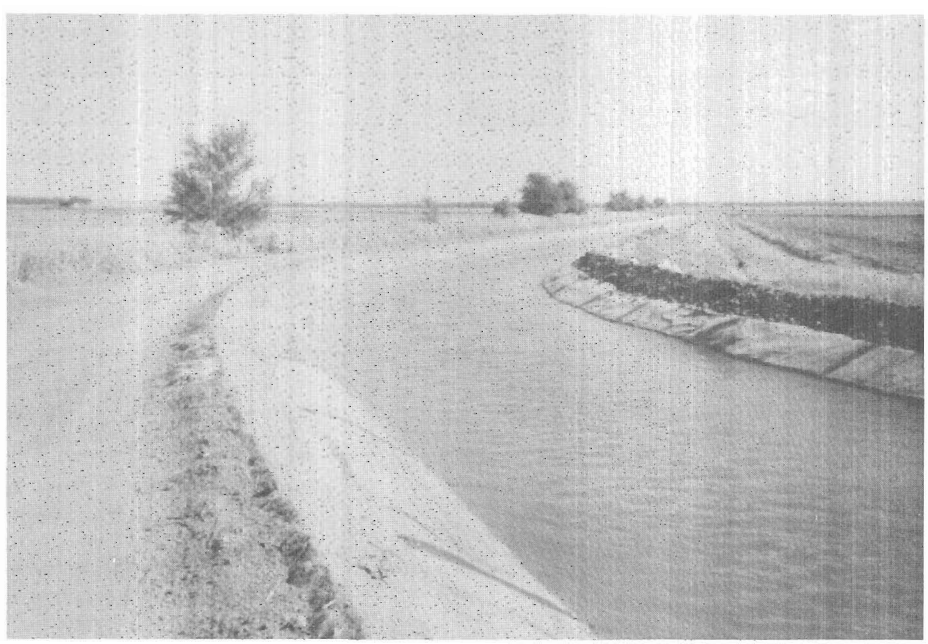
Photograph 20.—The white truck pulls the Teranap off the roll, assisted by the nearer, stationary truck, which is equipped with snatch block.



Photograph 21.— Snatch block on the rear bumper of the stationary truck.

Lugert-Altus Irrigation District - Test Section L-1
Exposed Teranap

Photograph 22.—Completed Teranap installation.



Photograph 23.—Completed installation. Water in canal flows 3 to 4 feet deep.

CHAPTER III
CONDITION ASSESSMENT

Visual Inspections

All 22 test sections have been visually inspected on a semi-annual basis to monitor lining condition, assess durability, and evaluate any maintenance requirements. The most recent inspections were performed in October 1996 when the Arnold test sections were 4 to 5 years old, the North Unit test sections were 4 to 4½ years old, the Tumalo test sections were 1½ to 2½ years old, and the Lugert-Altus test section was 2½ years old. The condition of each test section is summarized in tables 4, 5, and 6.

Table 4.—Five-Year Condition Assessment - Arnold Canal

	Test Section	2-Year Condition	4-5 Year Condition	Comments
A-1	Petromat with 3-inch shotcrete cover	Excellent	Excellent	No Problems
A-2	30-mil VLDPE with 3-inch shotcrete cover	Excellent	Excellent	No Problems
A-3	Exposed 80-mil HDPE	Very Good to Excellent	Very Good	Several small tears and cuts
A-4	Exposed Geolam	Excellent	Very Good	Several small tears and cuts Unbonded geotextile seams
A-5	Exposed 45-mil Hypalon	Excellent	Very Good	Several small tears and cuts
A-6	Exposed 36-mil Terra-Tuff	Very Good to Excellent	Very Good	Several small tears and cuts
A-7	40-mil PVC with 3-inch grout-filled mattress	Excellent	Excellent	No Problems
A-8	3-inch grout-filled mattress	Excellent	Excellent	No Problems
A-9	Exposed VLDPE with grout-filled mattress on side slopes only	Marginal	Removed from Study after 28 months	Liner "whales" were impeding flow
A-10	Exposed HDPE with grout-filled mattress on side slopes only	Marginal	Removed from Study after 28 months	Liner "whales" were impeding flow

Table 5.—Four-Year Condition Assessment - North Unit Main Canal

	Test Section	2-Year Condition	4- to 4½-Year Condition	Comments
N-1	SPF with Futura 500/550 Protective Coating	Partially Failed 25%*	Partially Failed 50%*	Partial Foam wash-out
N-2	SPF with Geothane 5020 Protective Coating	Partially Failed 10%*	Partially Failed 30%*	Partial Foam wash-out
N-3	Tietex Geotextile with Geothane 5020 Coating	Failed	Failed	Complete Failure (May 1993)
N-4	Tietex Geotextile with Geothane 5020 Coating	Failed	Failed	Complete Failure (May 1993)
N-6	3-inch Shotcrete with Novocon steel fibers	Excellent	Excellent	No Problems
N-7	3-inch Shotcrete with Phillips Polyfibers	Excellent	Excellent	No Problems
N-8	3-inch Shotcrete with Fibermesh Polyfibers	Excellent	Excellent	No Problems
N-9	3-inch Unreinforced Shotcrete	Excellent	Excellent	No Problems

* Percent failure = As a percentage of wetted perimeter

Table 6.—Two-Year Condition Assessment - Tumalo and Lugert-Altus Irrigation Districts

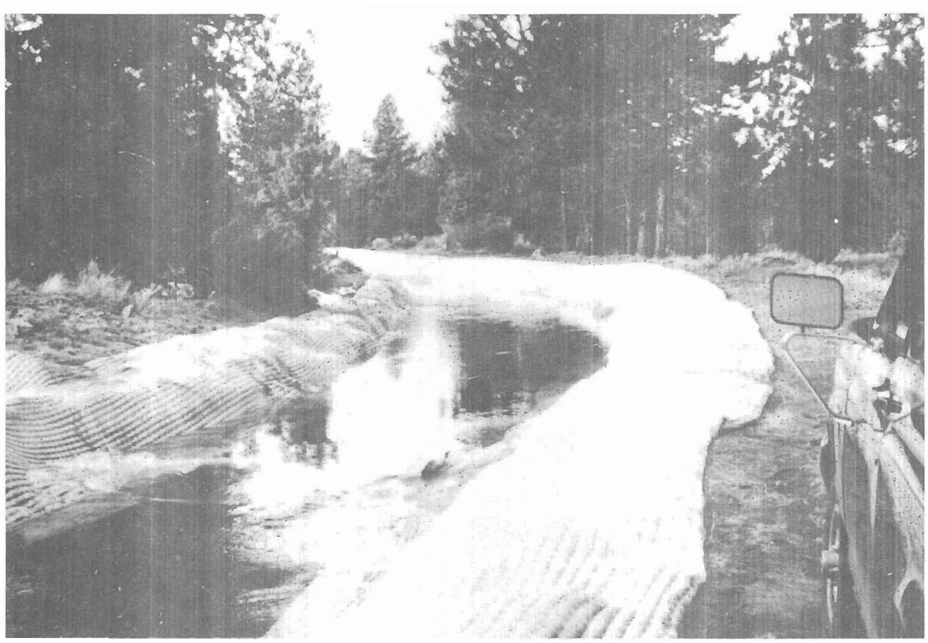
	Test Section	2-Year Condition	Comments
T-1	Liquid Boot over an Existing Concrete Flume	Poor	Disbonded from Invert
T-2	Liquid Boot over a Sandblasted Steel Flume	Very Good	40-50 blisters in the Invert
T-3	Liquid Boot over a Broomed Steel Flume	Very Good	About 40 blisters in the Invert
L-1	Exposed Teranap Geomembrane	Very Good	Partial wash-out has been repaired

Ice Jams.—Many canals, including the Arnold Canal, do not have adequate slope to drain when the water is turned off. Ponds form in these locations (typically 6 to 12 inches deep) and rain and snow add to the ponds. Before lining the Arnold Canal test sections, these ponds were not a problem because the water would slowly seep out of the unlined canal. However, since lining, this ponded water freezes, and ice remains in the canal throughout much of the winter. During winter water runs, ice collects at structures (bridges, siphons, etc.), restricting flow (see photographs 24 through 26) which can cause water to backup and overflow the canal banks. The Arnold Irrigation District has been forced to for go about half its traditional monthly winter water runs since the construction of the test sections. This problem was totally unanticipated. In the future, the possibility of ice jams should be considered when contemplating the rehabilitation (lining) of existing canals to reduce seepage.

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 3 inches of shotcrete or grout mattress lining. During construction of the test sections, special efforts were made to maintain the existing freeboard; however, the available freeboard may have been inadvertently reduced. These freeboard problems have become more critical in recent years as the district has increased its deliveries from the historical 54 cfs (5.5 gallons per minute [gpm] over 4,400 acres) to a new high of 64 cfs (6.5 gpm over 4,400 acres). Future lining installations should carefully consider the effect on available freeboard.

Photograph 24.—Ice jam forming on Test Section A-3 during a winter water run.

Photograph 25.—Ice jam forming on Test Section A-4 during a winter water run.



Photograph 26.—Ice jam forming on Test Section A-7 during a winter water run.

Maintenance Reports

Arnold, North Unit, Tumalo, and Lugert-Altus Irrigation Districts have been documenting maintenance activities and costs for each test section. The maintenance data sheets are included in appendix C and provide a description of all maintenance activities, as well as cost break-downs for materials, labor, and equipment. Maintenance activities and costs to date for each test section are summarized in tables 7, 8, and 9. Note that many test sections are in need of repairs that have not yet been performed.

Table 7.—Maintenance Costs - Arnold Canal

	Test Section	Maintenance Requirements	Maintenance Performed		Additional Maintenance Needed
			Description	Cost ($)	
A-1	Petromat with 3-inch Shotcrete cover	Minor	None	0	Patch 4-5 small holes in shotcrete Carefully remove sediment and debris
A-2	30-mil VLDPE with 3-inch Shotcrete cover	Minimal	None	0	None
A-3	Exposed 80-mil HDPE	Minimal	Concrete Pad at 20+00	$120	Patch 4-6 small tears in geomembrane
A-4	Exposed Geolam	Minor	Concrete Pad at 20+00 Concrete Patch at 20+20 Concrete Pad at 30+00	120 140 120 $380	Repair 1,000 ft of geotextile seams Repair tear in geomembrane at 20+31 Carefully remove sediment and debris
A-5	Exposed 45-mil Hypalon	Minor	Concrete Pad at 30+00	$120	Patch 1-2 small tears in geomembrane Remove sediment and debris
A-6	Exposed 36-mil Terra-Tuff	Minor	None	0	Patch several small tears in geomembrane Carefully remove sediment and debris
A-7	40-mil PVC with 3-inch grout-filled mattress	Minimal	None	0	Carefully remove sediment and debris
A-8	3-inch grout-filled mattres s	Minimal	None	0	Patch grout mattress at 54+50
A-9	Exposed VLDPE with grout-filled mattress on side slopes only	Extensive	Concrete Pad at 55+00 Contractor repaired geomembrane Ballast over whales Removed geomembrane from invert	240 3,000 3,000 7,500 $13,740	Test Section Abandoned
A-10	Exposed HDPE with grout-filled mattress on side slopes only	Extensive	Removed Cement deposits Contractor repaired geomembrane Ballast over whales Removed geomembrane from invert	320 3,000 3,000 7,500 $13,820	Test Section Abandoned

Table 8.—Maintenance Costs - North Unit Main Canal

	Test Section	Maintenance Requirements	Maintenance Performed		Additional Maintenance Needed
			Description	Cost ($)	
N-1	SPF with Futura 500/550 protective coating	Extensive	Removed washed-out foam at Siphon Installed weed rack at Siphon	1,387 240 $1,627	Needs extensive repairs Do not repair, continue to monitor
N-2	SPF with Geothane 5020 protective coating	Extensive	Removed washed-out foam at Siphon Installed weed rack at Siphon	1,387 240 $1,627	Needs extensive repairs Do not repair, continue to monitor
N-3	Tietex Geotextile with Geothane 5020 protective coating	Extensive	Patched holes in geotextile lining Removed washed-out geotextile lining Repaired damaged pipeline crossing	555 1,387 803 $2,745	None - complete failure; lining removed
N-4	Phillips Geotextile with Geothane 5020 protective coating	Extensive	Patched geotextile lining Removed washed-out geotextile lining Repaired damaged pipeline crossing	555 1,387 803 $2,745	None - complete failure; lining removed
N-6	3-inch Shotcrete with Novocon Steel Fibers	Minor	Patched 2 large holes in Shotcrete, and removed large rocks Caulked cracks in Shotcrete Patched small holes in Shotcrete	977 120 100 $1,197	None
N-7	3-inch Shotcrete with Phillips Polyfibers	Minimal	Patched small holes in Shotcrete	$100	None
N-8	3-inch Shotcrete with Fibermesh Polyfibers	Minimal	Patched small holes in Shotcrete	$100	None
N-9	3-inch unreinforced Shotcrete	Minimal	Patched small holes in Shotcrete	$100	None

Table 9.—Maintenance Costs - Tumalo and Lugert-Altus Irrigation Districts

	Test Section	Maintenance Requirements	Maintenance Performed		Additional Maintenance Needed
			Description	Cost	
T-1	Liquid Boot over an Existing Concrete Flume	Extensive	None	0	Needs extensive repairs Do not repair, continue to monitor
T-2	Liquid Boot over a Sandblasted Steel Flume	Minor	Patched Several blisters with Roofing Tar	$200	Patch 40-50 blisters in the Invert
T-3	Liquid Boot over a Broomed Steel flume	Minor	None	0	Patch about 40 blisters in the Invert
L-1	Exposed Teranap	Minor	Repaired Rainstorm Wash-out	$3,000	None

Arnold Canal

Test Section A-1.—

Material:	Petromat MB II with 3-inch shotcrete cover
Description:	Phillips Petromat MB II is a 4-mil polyethylene geomembrane with a 4-ounce non-woven geotextile bonded to each side.
Construction cost:	Petromat MB II with unreinforced shotcrete cover - $2.06 per square foot Petromat MB II with 1½-pound polyfiber shotcrete cover - $2.12 per square foot
Date Installed:	February 1992 (56 months old)
Location:	Station 0+00 to 10+00 (1,000 linear feet; 30,000 square feet)
Condition:	Excellent - After almost 5 years service, the shotcrete lining is in excellent condition, completely protecting the underlying Petromat geosynthetic liner from weathering and mechanical damage. The only significant damage is that the shotcrete cover is showing extensive cracking over the anchor trench where the shotcrete was tapered-down to a thickness of less than 1 inch. Tapering of the shotcrete over the anchor trench is not recommended for future installations, instead the shotcrete should maintain a minimum thickness of 2 inches over the anchor trench. No freeze/thaw damage has occurred. Most of the invert has standing water, typically 6 to 12 inches deep, but up to 2 feet deep in places. Lots of debris has collected in the canal. Sediment is 6 to 12 inches deep in many parts of the test section. The first half of the test section (approximately 400 linear feet) contains 1½ lb/yd^3 polyfiber reinforcement. The upstream cut-off trench is holding up well. Transverse cracks have developed in the side walls about every 100 feet. Where not covered by standing water, random cracks are sometimes visible in the invert. Many of the cracks have been marked with spray paint to aid in the detection of new cracks. The fire-red spray paint is holding up best, while the fluorescent orange weathers away rather quickly. Some new cracks develop every year, and many of the old cracks are growing in length, but not widening significantly. The second half of the test section (about 600 linear feet) has more transverse cracking (about every 50 feet) but predominantly in the north (south-facing) side wall. The transverse and longitudinal cracks in the shotcrete are not considered detrimental because the geomembrane underliner provides the seepage control, while the shotcrete cover protects the geomembrane from weathering, ultraviolet

light, mechanical damage, vandalism, and animal damage. This shotcrete also has developed some minor random cracking over the anchor trench where the shotcrete tapers off.

In March 1994, about 100 linear feet of this test section was torn out and replaced when the Highway 97 bridge (approximately station 7+00) was widened from two lanes to four. The new replacement lining uses the same construction materials and techniques as the old lining (Petromat with 3-inch shotcrete cover). This replacement liner is holding-up well, with the exception of some disbonded shotcrete on the side walls under the new bridge. Costs for this lining replacement will not be 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 (test sections with exposed geomembrane did not fare so well - see Test Section A-3).

Maintenance: Minimal maintenance required to date

Performed: None

Needed: Need to patch several holes in the shotcrete lining (at the waterline) at the downstream end of this test section (approximately station 9+00).

To improve hydraulic flow, the irrigation district plans to remove sediment and debris from this test section before the next irrigation season. Operation of small rubber-tired equipment (Bobcat) within the canal prism should not be a problem. Also, a skilled back-hoe operator should have no trouble removing the sediments without damaging the shotcrete. Some care should be taken not to dislodge the thin shotcrete over the anchor trench. Since sediment removal is normal maintenance for both lined and unlined canals, only the additional costs (if any) associated with the careful removal of sediments from the shotcrete lining will be included in the life-cycle cost analysis.

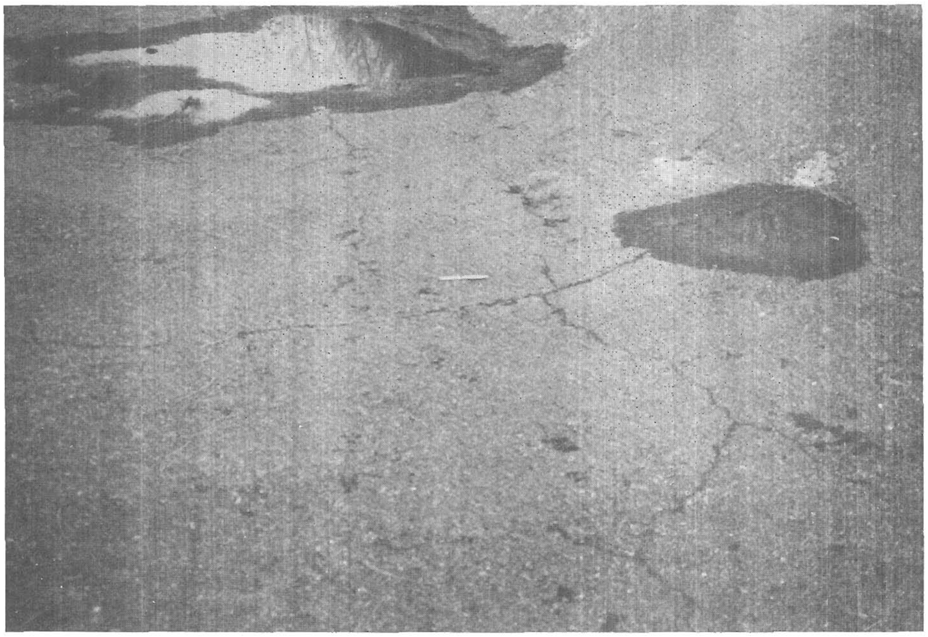
Photographs: 27 through 34

Arnold Canal - Test Section A-1
Petromat with 3-inch shotcrete cover

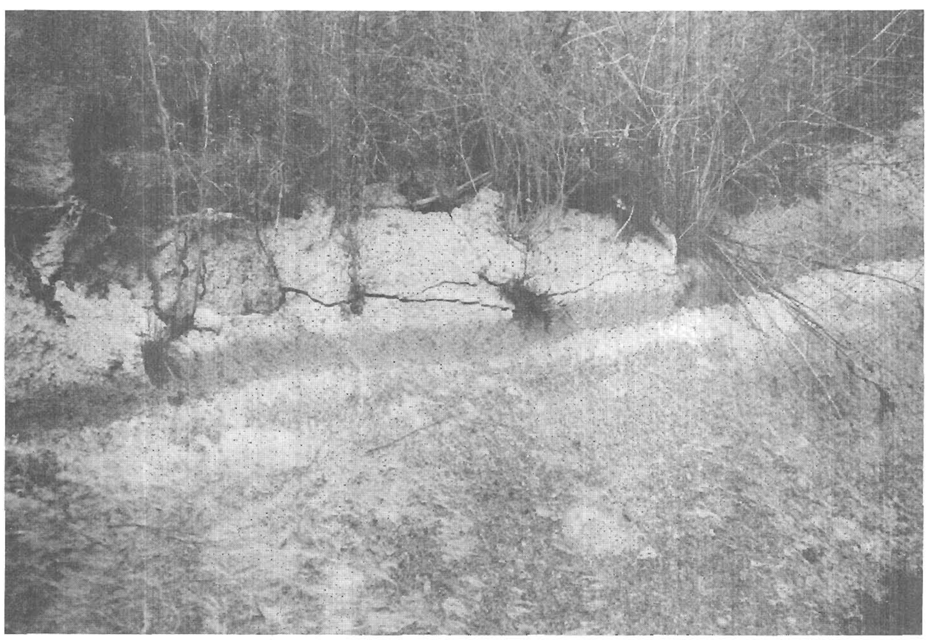
Photograph 27.—Excellent condition after almost 5 years of service.

Photograph 28.—Lots of sediment and debris have collected in the canal.

Arnold Canal - Test Section A-1
Petromat with 3-inch shotcrete cover



Photograph 29.—In one of the few areas not covered with standing water, random cracks are visible in the invert as well as the side walls.



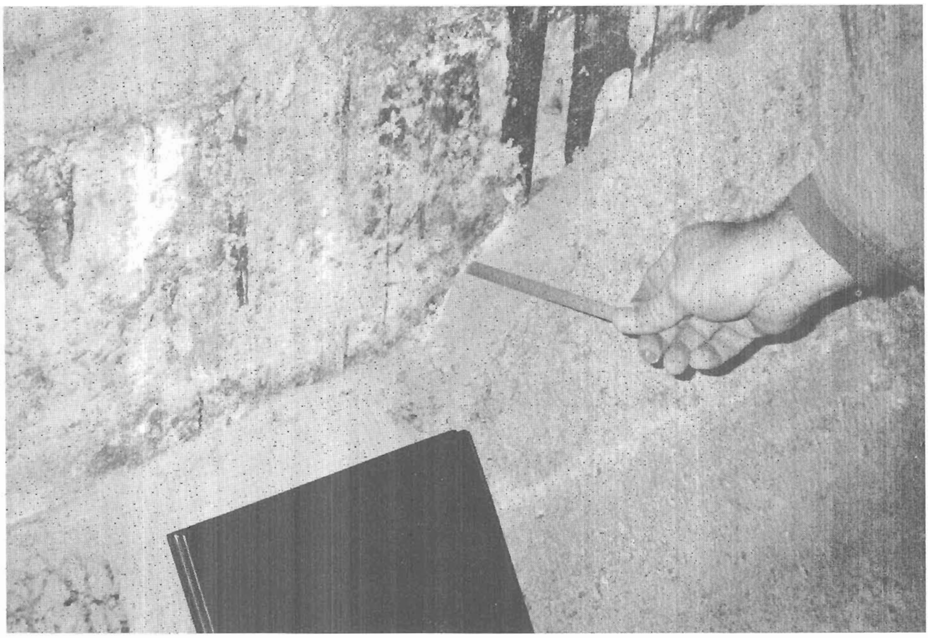
Photograph 30.—Cracking is most pronounced at the top of the side walls where the shotcrete thickness tapers down to 1 inch or less.

Arnold Canal - Test Section A-1
Petromat with 3-inch shotcrete cover

Photograph 31.—Petromat does not extend far enough up the side slope at this location (approximately station 9+00), and a few holes in the shotcrete lining need to be patched to prevent erosion of embankment behind the shotcrete lining.

Photograph 32.—New bridge and lining at Highway 97.

Arnold Canal - Test Section A-1
Petromat with 3-inch shotcrete cover



Photograph 33.—Some shotcrete lining in tunnel beneath the new bridge has disbonded but remaining shotcrete appears stable.

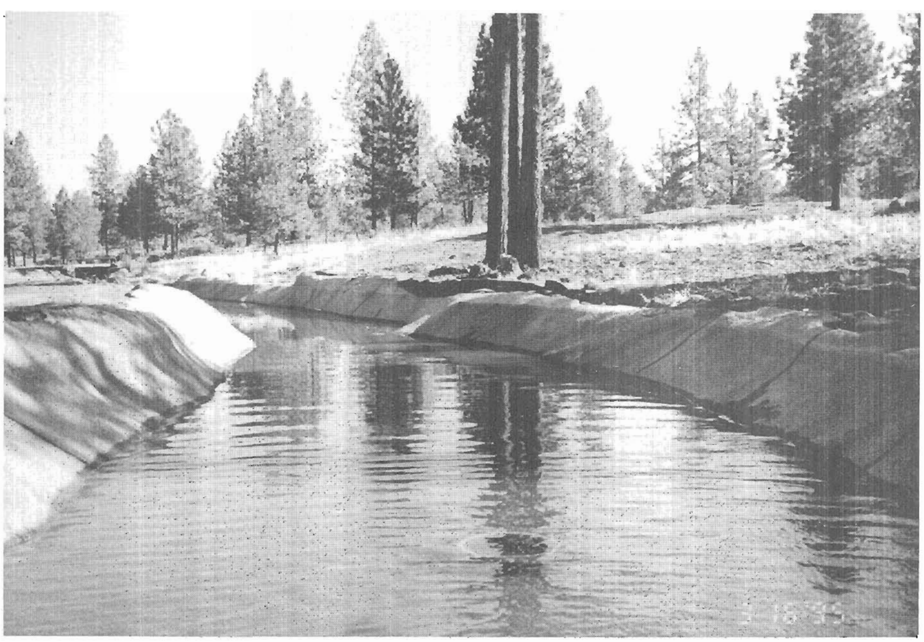
Photograph 34.—A 1994 windstorm deposited this tree in the canal with no damage to the shotcrete lining. The exposed geomembranes did not fare so well.

Test Section A-2.—

Material:	30-mil textured VLDPE with 16-ounce geotextile cushion and 3-inch shotcrete cover
Description:	The VLDPE liner is 30-mil Gundle textured Hyperelastic. The geotextile cushion is Polyfelt TS-1000, a 16-ounce, needle-punched, non-woven geotextile.
Construction Cost:	$2.14 per square foot
Date Installed:	October 1992 (48 months 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 geosynthetic liner. After 4 years, no freeze/thaw damage has been observed. Most of the invert is covered with standing water. Little to no sediment has collected in the canal invert. Dozens of transverse contraction cracks have developed on each bank (every 10 to 20 feet). Two transverse cracks (station 13+00 estimated) extend completely across the canal prism and measure up to 3/16 inch wide. Some new cracks appear every year, and many of the old cracks grow in length but do not widen significantly. 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. The owner of the golf course adjacent to the canal has installed fencing and planted grass right up to the canal prism (see photo 35). These improvements may be infringing on the districts maintenance right-of-way.
Maintenance:	Minimal maintenance requirements to date Performed: None Needed: None.
Photographs:	35 through 40

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

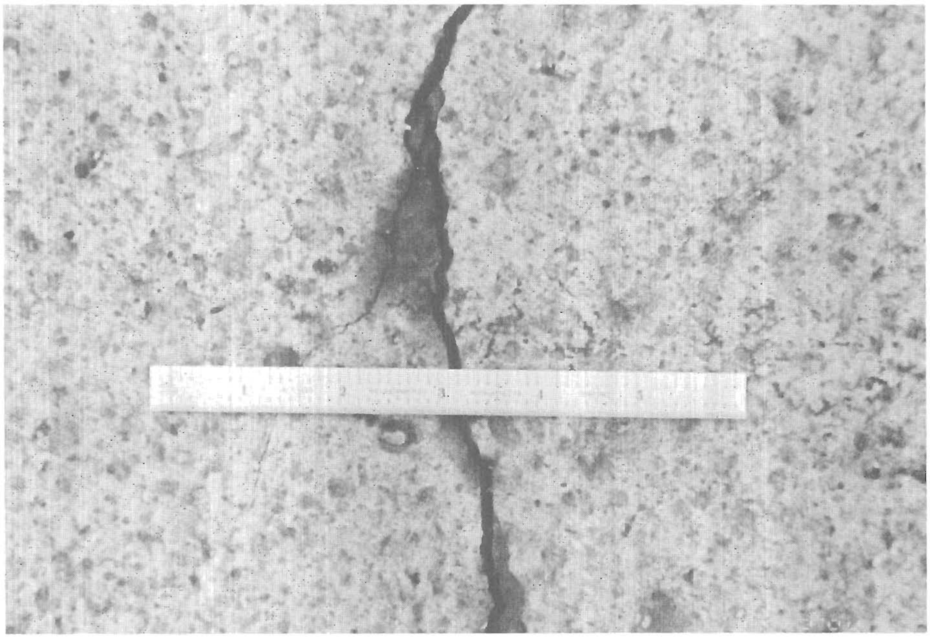
Photograph 35.—Canal overview - excellent condition after 4 years of service. Landowner has installed fencing and planted grass adjacent to the canal.



Photograph 36.—Old tire is typical of debris found in the canal.

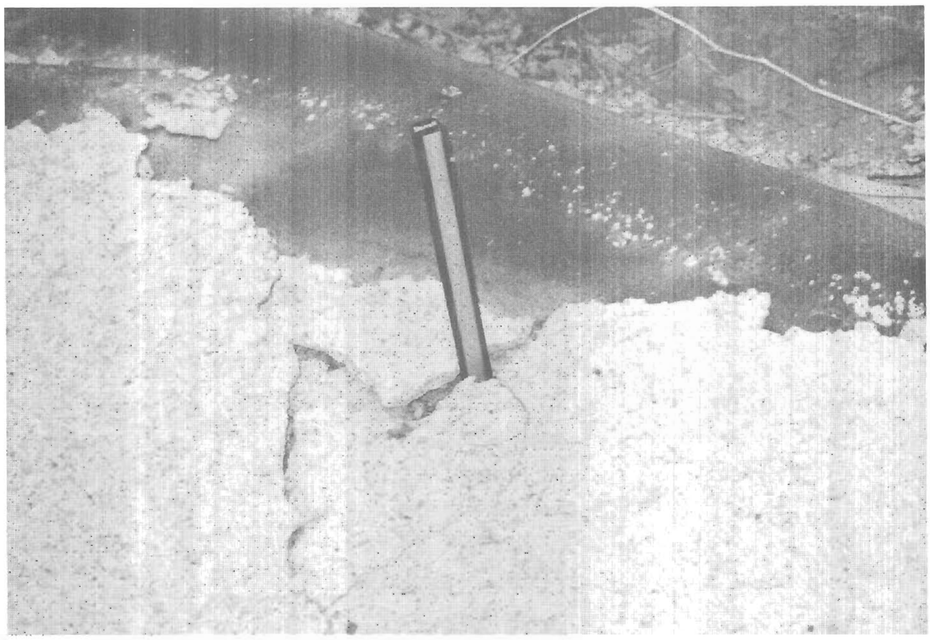
Arnold Canal - Test Section A-2
30-mil textured VLDPE with 16-ounce geotextile cushion and 3-inch shotcrete lining

Photograph 37.—Transverse contraction cracks are common in the side walls.

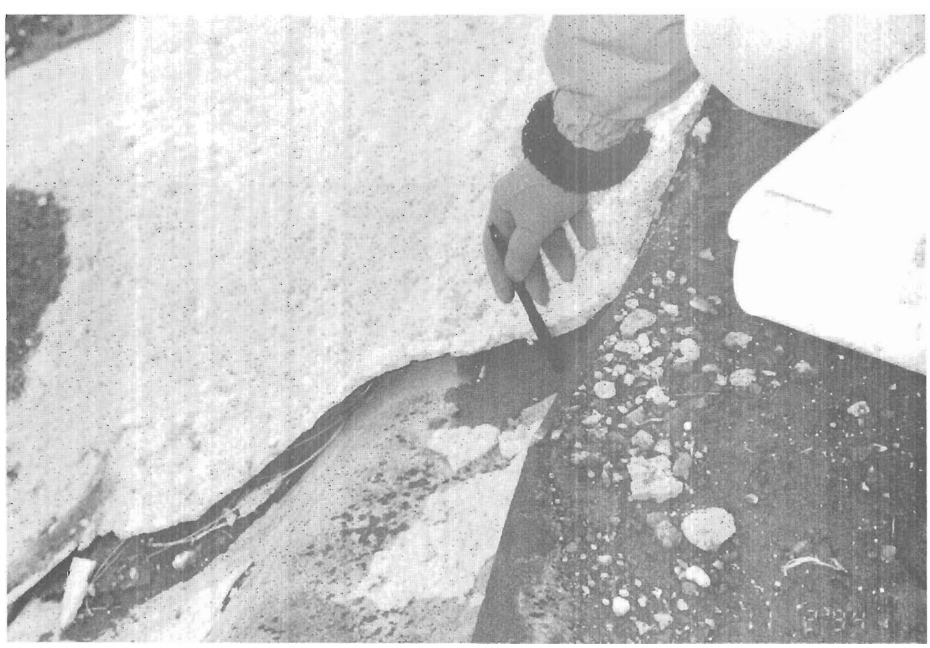


Photograph 38.—Largest cracks measure up to 3/16 inch wide and extend completely across the canal.

Arnold Canal - Test Section A-2
30-mil textured VLDPE with 16-ounce geotextile cushion and 3-inch shotcrete lining



Photograph 39.—Thin shotcrete over anchor trench is breaking up.



Photograph 40.—Thin shotcrete over anchor trench is less than 1-inch thick.

Test Section A-3.—

Material:	Exposed 80-mil textured HDPE
Description:	HDPE liner is Gundle 80-mil textured Gundline HDT
Construction Cost:	$1.38 per square foot
Date Installed:	October 1992 (48 months old)
Location:	Station 15+00 to 20+00 (500 linear feet; 15,000 square feet)

Condition:

Very Good - After 4 years of service, the exposed HDPE liner is in very good condition, with little to no sediment in the invert. About half of this test section has standing water, typically 6 to 12 inches deep. A small tear at the upstream end (station 15+00) is probably from a backhoe removing the dike after the post-construction ponding tests. A small (3-inch long) tear or cut was found in the invert (station 16+00). A semicircular tear (perhaps from an animal hoof) was found on the left bank above the water line (station 18+50). The anchor trench on the left bank (6 to 12 inches wide by 6 to 12 inches deep) is holding up well. The rock cover (in lieu of an anchor trench) on the right bank is also performing satisfactorily. Little freeboard is available on the right bank; however, the extra HDPE beneath the rock cover is sufficient to increase the freeboard if needed. At station 19+80 (estimated), the HDPE is torn where stretched tightly over a rock. The stainless steel battens at the bridge (station 17+50) are in excellent condition. The battens measure 2 inches wide by 3/16 inch 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.

The owner of the golf course adjacent to the canal has installed fencing and planted grass right up to the canal prism (see photo 41). These improvements may be infringing on the districts maintenance right-of-way. Also, runoff from watering the grass could cause stability problems in the canal side slopes.

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 (A-3 cost = $120).

Needed: Patch four to six small tears in the liner. To perform repairs, Reclamation plans to purchase a small hand-held thermal welder.

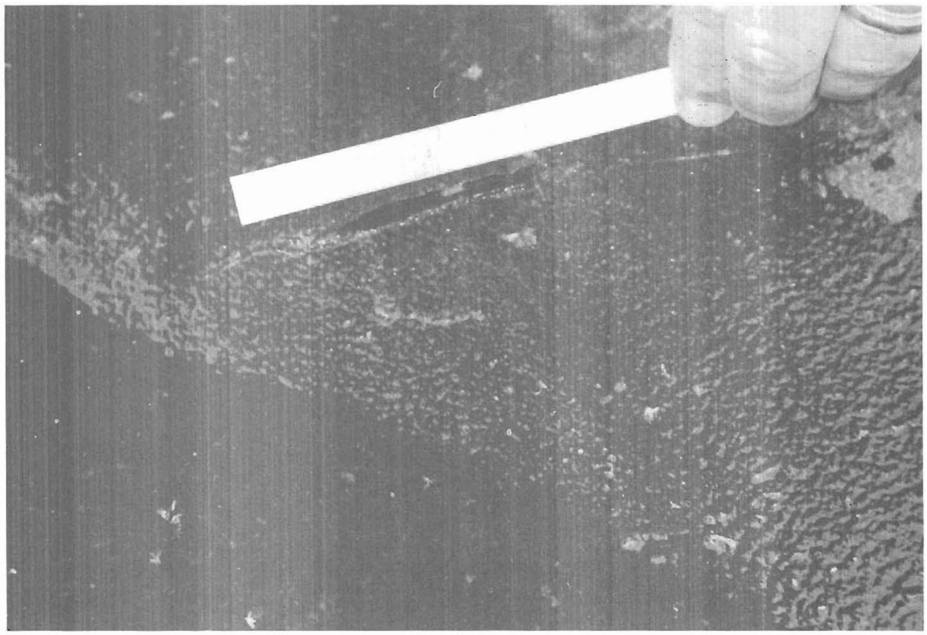
Photographs: 41 through 46

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

Photograph 41.—Canal overview - very good condition after 4 years of service.

Photograph 42.—Small tears (station 15+00) were probably caused by a backhoe during removal of the earthen dikes used for the post-construction ponding tests.

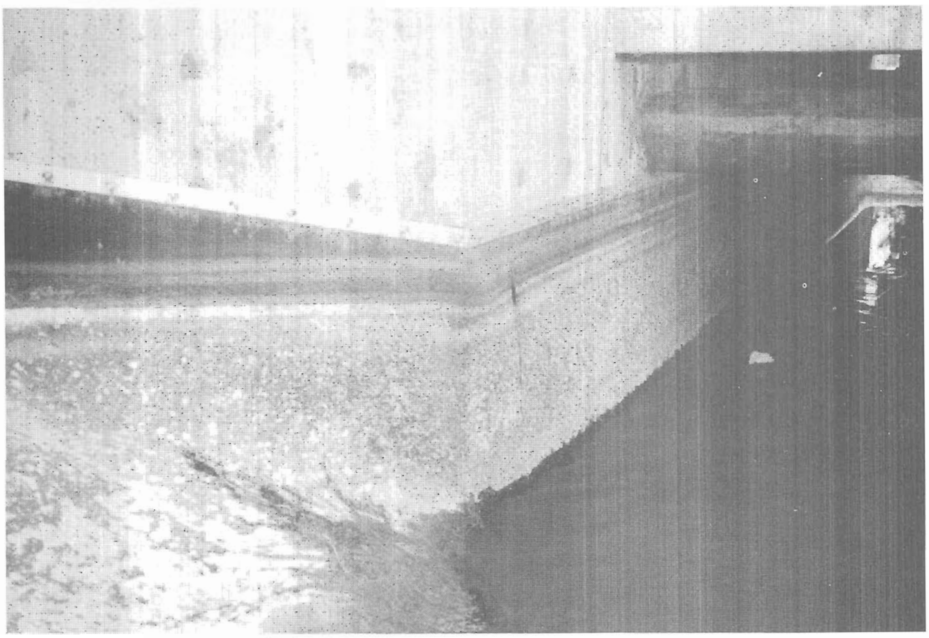
Arnold Canal - Test Section A-3
Exposed 80-mil textured HDPE



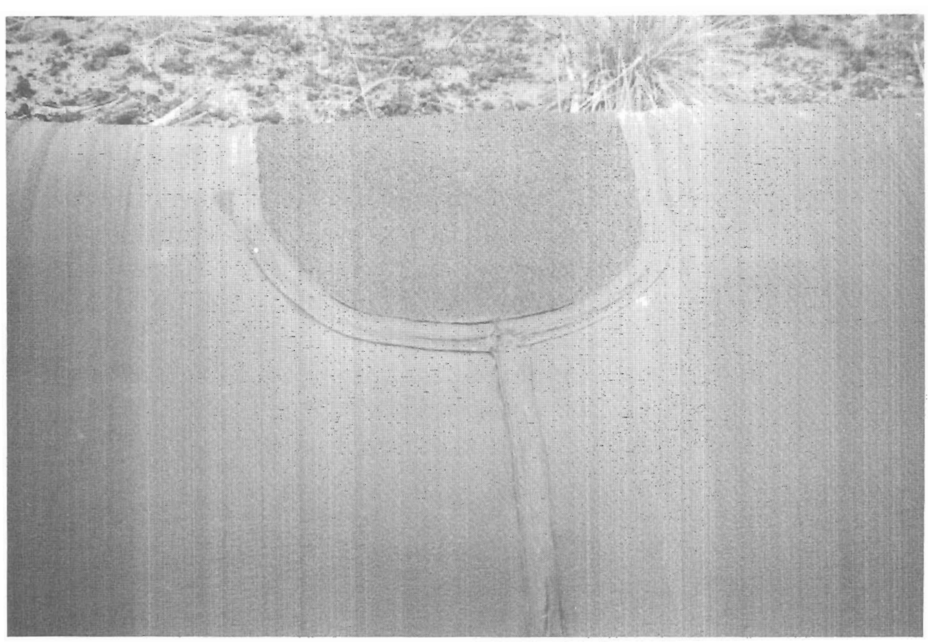
Photograph 43.—Small tear in the liner at station 16+00.

Photograph 44.—Limited freeboard on the right-hand bank.

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



Photograph 45.—Stainless steel batten strips on bridge are in excellent condition.



Photograph 46.—Large variations in the degree of texturing are evident.

Test Section A-4.—

Material:	Inverted Geolam with 6-ounce geotextile cushion
Description:	Geolam is a PVC/geotextile composite consisting of 30-mil Occidental PVC geomembrane bonded to a Trevira 6-ounce needle-punched, non-woven geotextile.
Construction Cost:	$1.05 per square foot
Date Installed:	March 1992 (55 months old)
Location:	Station 20+00 to 30+00 (1,000 linear feet, 30,000 square feet)

Condition:

Very Good - After 4½ years of service, performing much better than expected. The PVC is holding up well with no visible deterioration or stiffening, even where exposed. The PVC may be experiencing a slight color change from gray to white where exposed above the waterline. The four longitudinal PVC seams are in very good condition. The geotextile is slowly weathering away (especially where unbonded at seams). The most severe weathering may prove to be at the waterline where the Geolam is exposed to wet/dry cycles. About 25 percent of the geotextile seams need to be closed. Seaming of the geotextile with hog-rings has proven to be only partially effective. Recommend sewing or thermal bonding.

A great deal of sediment (up to 12 inches) has collected between stations 23+00 and 27+00, and aquatic vegetation is growing in the sediment. "Scuffing" of the geotextile along the top of each berm is probably caused by animals or workers entering and exiting the canal.

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

Maintenance:

Minor maintenance required to date

Performed: In 1994, the district placed concrete anchor pads between test sections A-3 and A-4 at station 20+00 (A-4 cost = $120), and between test sections A-4 and A-5 at station 30+00 (A-4 cost = $120). The district also repaired one small tear at station 28+50 by placing a

1-foot by 1-foot concrete cap over the tear, and placed a 10-foot by 10-foot concrete pad in the invert at 20+20 to repair backhoe damage (cost = $140).

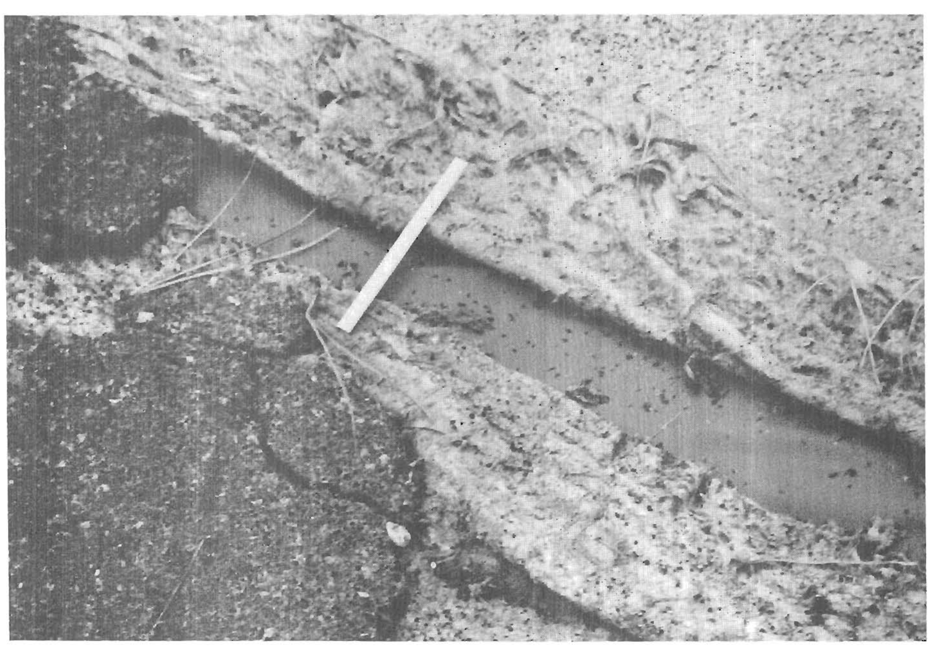
Needed: To improve hydraulic flow, the irrigation district plans to remove sediment and debris from this test section before the next irrigation season. Great care should be taken not to damage the exposed geomembrane during cleaning. All standing water should be pumped out of the test section prior to cleaning to improve visibility. Bulk sediment deposits can then be carefully removed with a backhoe to within 1 inch of the liner. The remaining sediments should then be either left in place or carefully removed by hand with a round-point shovel. Equipment should not be allowed to operate within the canal prism. Since sediment removal is normal maintenance for both lined and unlined canals, only the additional costs associated with the careful removal of sediments from the exposed geomembrane will be included in the life-cycle cost analysis.

About 1,000 feet of geotextile seams need to be sewn or thermally welded to protect PVC geomembrane from UV degradation. Need to repair a small tear in liner at 20+30. To perform future repairs to the geomembrane, the irrigation district needs PVC solvent cement, extra Geolam, and some hands-on training.

Photographs: 47 through 54

Arnold Canal - Test Section A-4
Inverted Geolam with 6-ounce geotextile cushion

Photograph 47.—Canal overview - very good condition after 4½ years of service.



Photograph 48.—Many of the geotextile seams need to be sewn or thermally welded.

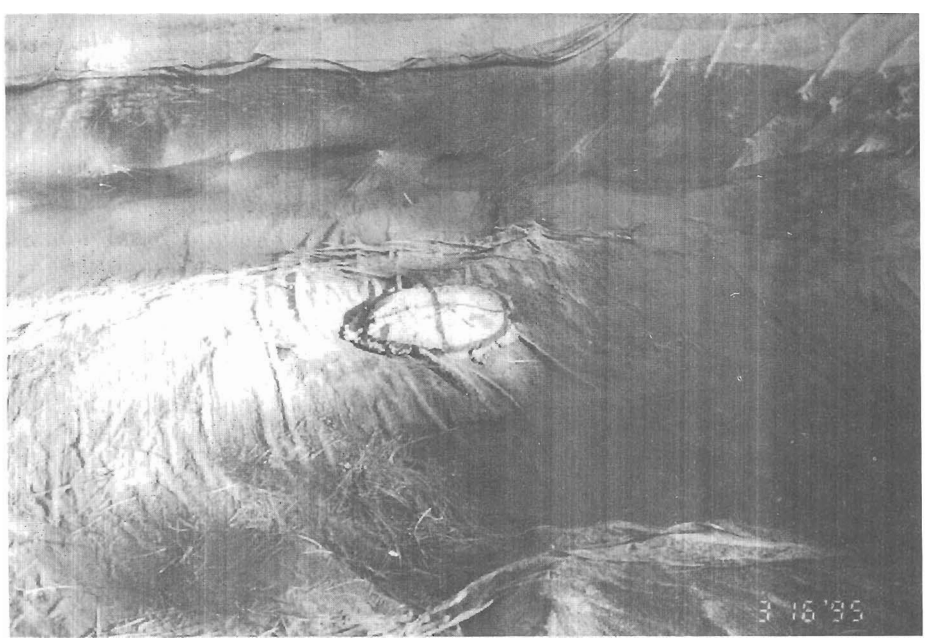
Arnold Canal - Test Section A-4
Inverted Geolam with 6-ounce geotextile cushion

Photograph 49.—Tears in geomembrane liner caused by a backhoe.

Photograph 50.—Irrigation district used a 10-foot by 10-foot concrete patch to repair tears in the geomembrane liner.

Arnold Canal - Test Section A-4
Inverted Geolam with 6-ounce geotextile cushion

Photograph 51.— A great deal of sediment has collected in the canal around this bend at stations 23+00 to 27+00.



Photograph 52.—Small (1-foot diameter) concrete patch at station 28+50.

Arnold Canal - Test Section A-4
Inverted Geolam with 6-ounce geotextile cushion

Photograph 53.—A 1994 windstorm deposited a tree in the canal, tearing the geomembrane liner.

Photograph 54.—Close-up of tear needing repair.

Test Section A-5.—

Material:	Exposed 45-mil Hypalon with 16-ounce geotextile cushion
Description:	The Hypalon membrane is JP Stevens 45-mil CSPE-R (reinforced chlorosulfonated polyethylene). The geotextile cushion is Polyfelt TS-1000, a 16-ounce, needle-punched, non-woven geotextile.
Construction Cost:	$1.11 per square foot
Date Installed:	March 1992 (55 months old)
Location:	Station 30+00 to 35+00 (500 linear feet; 15,000 square feet)
Condition:	Very Good - The exposed Hypalon geomembrane and longitudinal seams are holding up well. Standing water covers almost the entire invert, typically 6 to 12 inches deep. The majority of the canal has several inches of sediment, with vegetation growing in the sediment. The upstream transition between Test Sections 4 and 5 (station 30+00) has been covered with a 7-foot concrete cap, which is working well. A surveying stake has been driven through the Hypalon liner on the left bank, but is well above the waterline. A couple of small tears have developed at the anchor trench (stations 31+00 left and 33+00 right), and a sharp subgrade rock has punctured the liner at the waterline (station 33+20). The right canal bank is unstable and has noticeable sloughing beneath the liner (approximately stations 33+00 to 33+50).
Maintenance:	Minor maintenance required

Performed:	In 1994, the district placed a concrete anchor pad between test sections A-4 and A-5 at station 30+00 (A-5 cost = $120).
Needed:	Patch a couple of small tears in the geomembrane. To improve hydraulic flow, the irrigation district plans to remove sediment and debris from this test section before the next irrigation season. Great care should be taken not to damage the exposed geomembrane during cleaning. All standing water should be pumped out of the test section prior to cleaning to improve visibility. Bulk sediment deposits can then be carefully removed with a backhoe to within 1 inch of the liner. The remaining sediments should then be either left in place or carefully removed by hand with a round-point shovel. Equipment should not be allowed to operate within the canal prism. Since sediment removal is

normal maintenance for both lined and unlined canals, only the additional costs associated with the careful removal of sediments from the exposed geomembrane will be included in the life-cycle cost analysis.

Photographs: 55 through 60

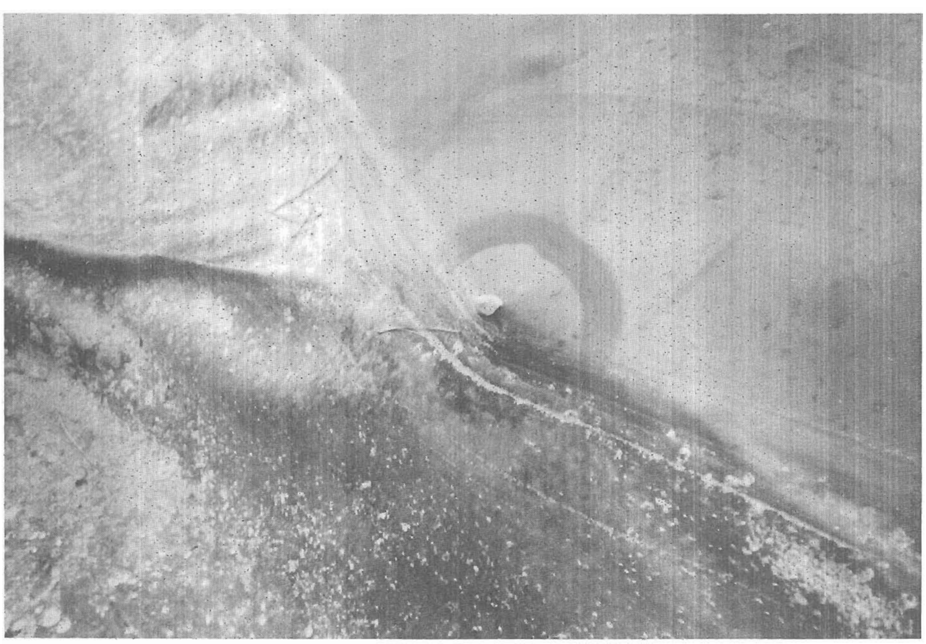
Arnold Canal - Test Section A-5
Exposed 45-mil Hypalon with 16-ounce geotextile cushion

Photograph 55.—Canal overview - very good condition after 4½ years of service.

Photograph 56.—Concrete cap at the upstream transition is working well.

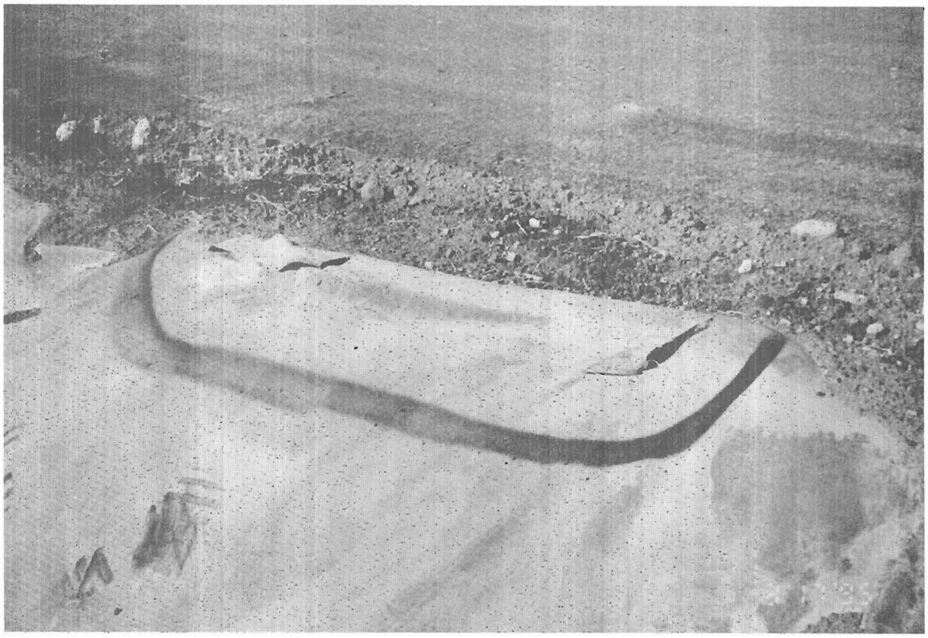
Arnold Canal - Test Section A-5
Exposed 45-mil Hypalon with 16-ounce geotextile cushion

Photograph 57.—Sloughing of the embankment beneath the geomembrane liner (stations 33+00 to 35+50).

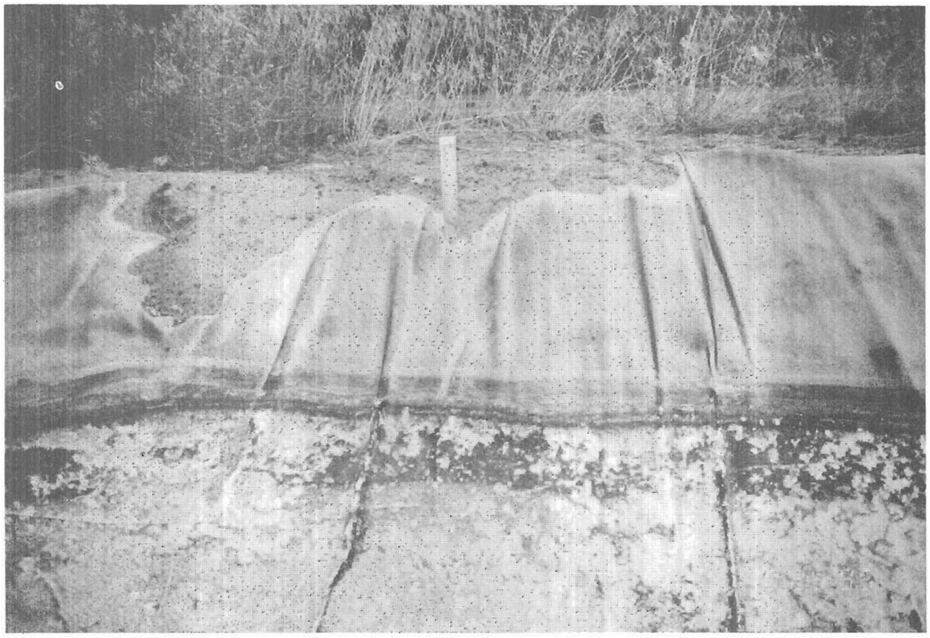


Photograph 58.—Sharp subgrade stick has punctured the liner at station 33+20.

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



Photograph 59.—Two small tears at the anchor trench.



Photograph 60.—Survey stake driven through the geomembrane liner. Fortunately, the stake is well above the waterline.

Test Section A-6.—

Material: Exposed 36-mil Terra-Tuff

Description: JP Stevens Terra-Tuff 801-R is a geocomposite consisting of 36-mil reinforced Hypalon laminated to an 8-ounce non-woven PET (polyethylene terephthalate) geotextile cushion.

Construction Cost: $1.03 per square foot

Date Installed: March 1992 (55 months old)

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

Condition: Very Good - After 4½ years, the exposed Hypalon geomembrane and longitudinal seams are holding up well. Standing water covers most of the invert, typically 6 to 12 inches deep. The majority of the canal has several inches of sediment, with vegetation growing underwater. The upstream transition between Test Sections 5 and 6 (station 35+00) has a transverse adhesive-bonded Hypalon/Hypalon seam which is working well. A concrete cap at this location would facilitate future ponding tests.

A small tear in the Hypalon at the anchor trench (station 35+00 left) needs to be repaired. At station 39+90, a large tear on the left bank (probably caused by a backhoe during dike removal) needs to be repaired. At station 39+95, several large cuts were made to relieve trapped water. These cuts allow some water to leak out of the canal, but they also allow any water trapped beneath the liner to escape. These tears need to be repaired to more fully evaluate the performance of the exposed Hypalon liners. At station 40+00, the Terra-Tuff liner is connected to the adjacent grout-filled mattress (Test Section 7) by batten strips, which are functioning satisfactorily. In the future, any dikes built between Test Sections 6 and 7 should be constructed on the grout-filled mattress in Test Section 7, not on the exposed Hypalon in Test Section 6.

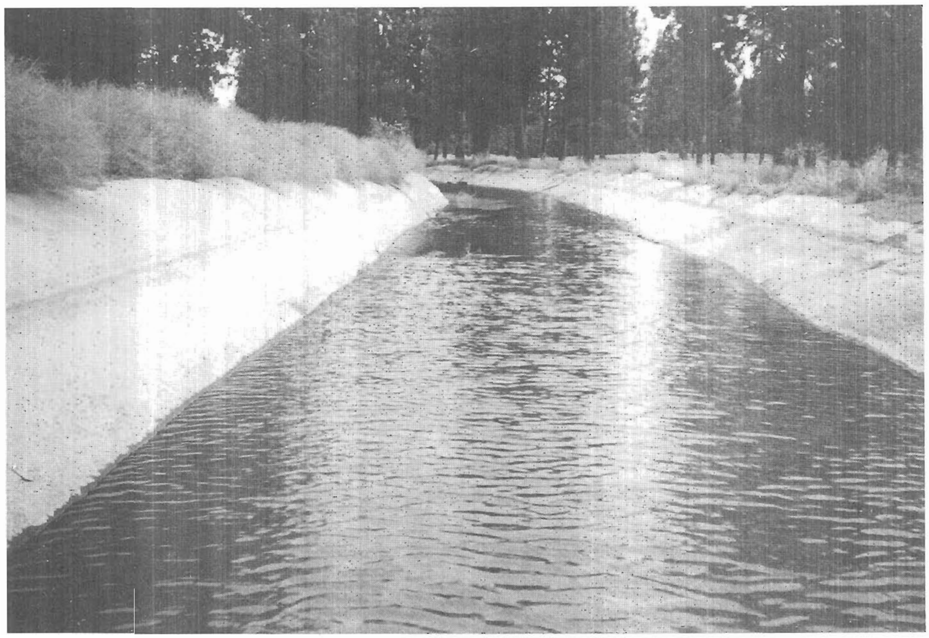
Maintenance: Minor maintenance required to date

Performed: None

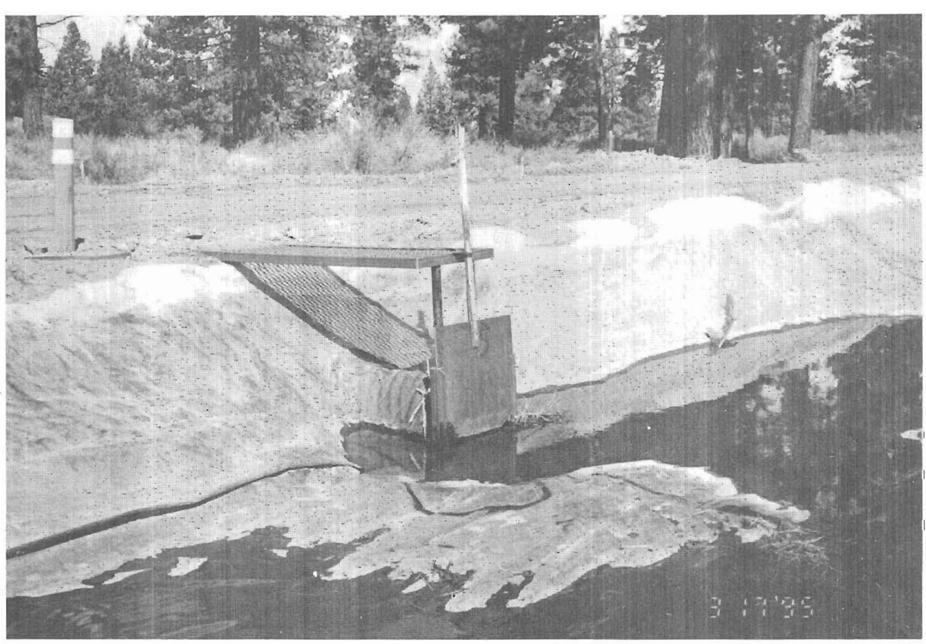
Needed: Need to patch several small tears and cuts, especially at the downstream transition. To improve hydraulic flow, the irrigation district plans to remove sediment and debris from this test section before the next irrigation season. Great care should be taken not to damage the exposed geomembrane during cleaning. All standing water should be pumped out of the test section prior to cleaning to improve visibility. Bulk sediment deposits can then be carefully removed with a backhoe to within 1 inch of the liner. The remaining sediments should then be either left in place or carefully removed by hand with a round-point shovel. Equipment should not be allowed to operate within the canal prism. Since sediment removal is normal maintenance for both lined and unlined canals, only the additional costs associated with the careful removal of sediments from the exposed geomembrane will be included in the life-cycle cost analysis.

Photographs: 61 through 65

Arnold Canal - Test Section A-6
Exposed 36-mil Terra-Tuff Geomembrane



Photograph 61.—Canal overview - very good condition after 4½ years of service.

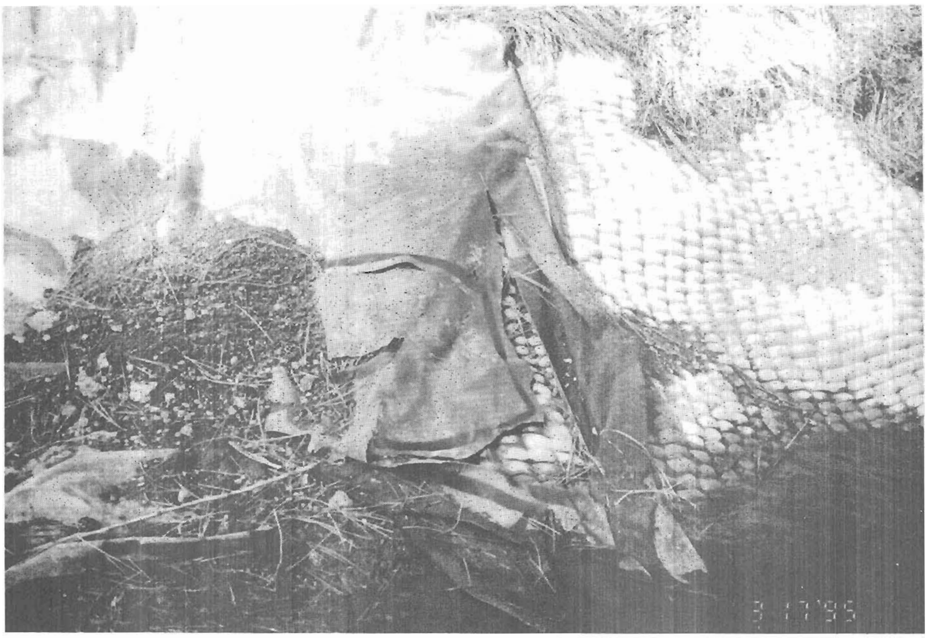


Photograph 62.—At the time of construction, the installer repaired several small tears around the golf course turn-out. All patches look good and are holding up well.

Arnold Canal - Test Section A-6
Exposed 36-mil Terra-Tuff Geomembrane

Photograph 63.—Station 37+00 - Irrigation district excavates anchor trench to investigate subsidence - no cause for the subsidence was found.

Photograph 64.—Several small tears at the downstream end (station 40+00) are in need of repair.



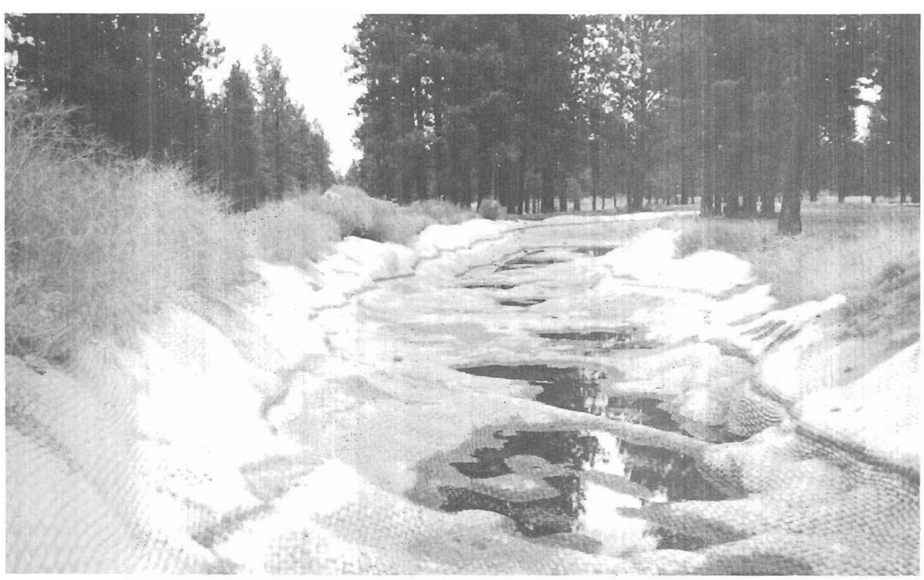
Photograph 65.—Close-up of backhoe damage to the geomembrane (station 40+00).

Test Section A-7.—

Material:	40-mil PVC with 3-inch grout-filled mattress
Description:	40-mil Occidental Oxyflex PVC membrane with Nicolon Armorform 3-inch USM (Uniform Section Mat) grout-filled mattress
Construction Cost:	$2.36 per square foot
Date Installed:	November 1991 (59 months old)
Location:	Station 40+00 to 48+00 (800 linear feet; 24,000 square feet)
Condition:	Excellent - The grout-filled mattress is in excellent condition with only small occasional defects. The grout-filled mattress is completely protecting the underlying PVC geomembrane. After 5 years of service, no freeze/thaw damage has occurred. 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 a great deal of sediment (up to 1 foot deep), underwater vegetation, and 6 to 12 inches of standing water. The second 300 feet has no sediment and no standing water, suggesting higher velocities and slope to drain. The outer fabric of the grout mattress is beginning to deteriorate, especially where subjected to abrasion. Above the waterline, the geotextile is quite weak and tears easily. When water is shut off in the fall, this test section holds standing water all winter, while the adjacent Test Section A-8 holds standing water for only a couple of weeks. This side-by-side comparison demonstrates the lower seepage rate of the grout-filled mattress with a geomembrane underliner.
Maintenance:	No maintenance required to date Performed: None Needed: To improve hydraulic flow, the irrigation district plans to remove sediment and debris from this test section before the next irrigation season. Operation of small rubber-tired equipment (Bobcat) within the canal prism should not be a problem. Also, a skilled back-hoe operator should have no trouble removing the sediments without damaging the grout-filled mattress. Since sediment removal is normal maintenance, only the additional costs (if any) associated with careful removal of sediments from the grout-filled mattress will be included in the life-cycle cost analysis.
Photographs:	66 through 72

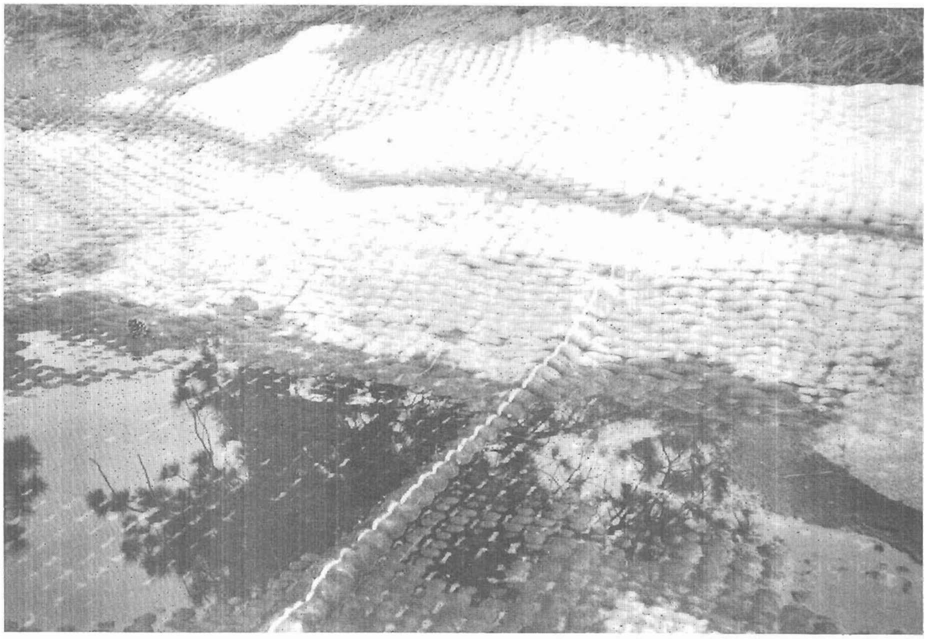
Arnold Canal - Test Section A-7
40-mil PVC with 3-inch grout-filled mattress

Photograph 66.—Canal overview - excellent condition after 5 years of service. The first 500 feet of this test section has a great deal of sediment and standing water.

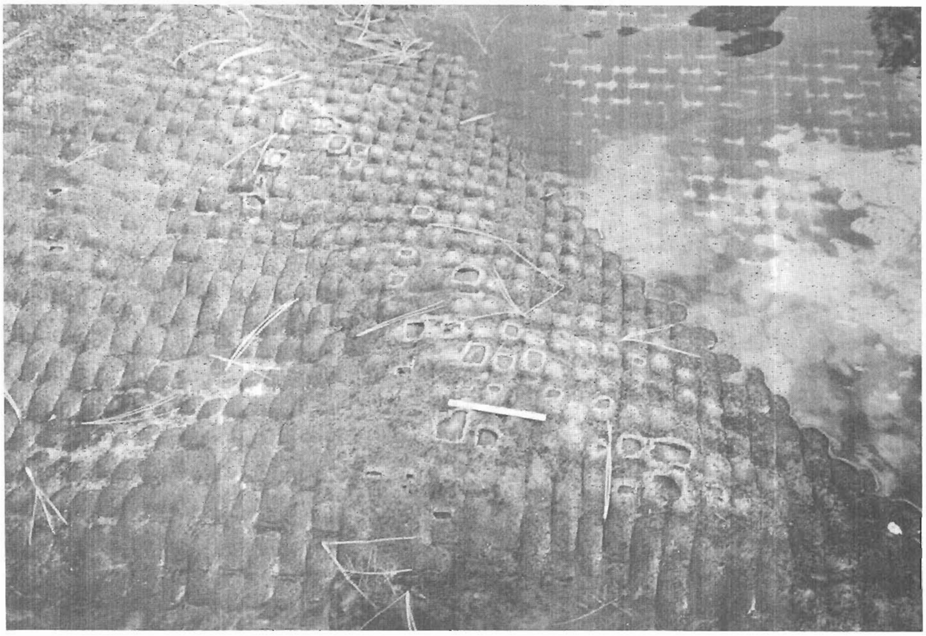


Photograph 67.—The second 300 feet has no sediment or standing water, indicating higher velocities and a steeper slope.

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

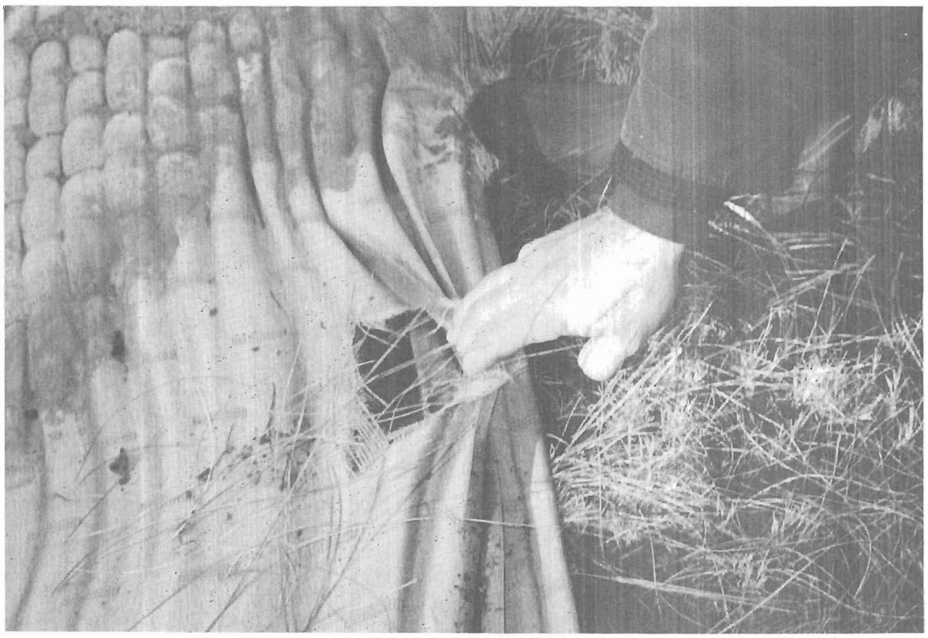


Photograph 68.—Factory installed zippers are performing well and give a tidy finished appearance.

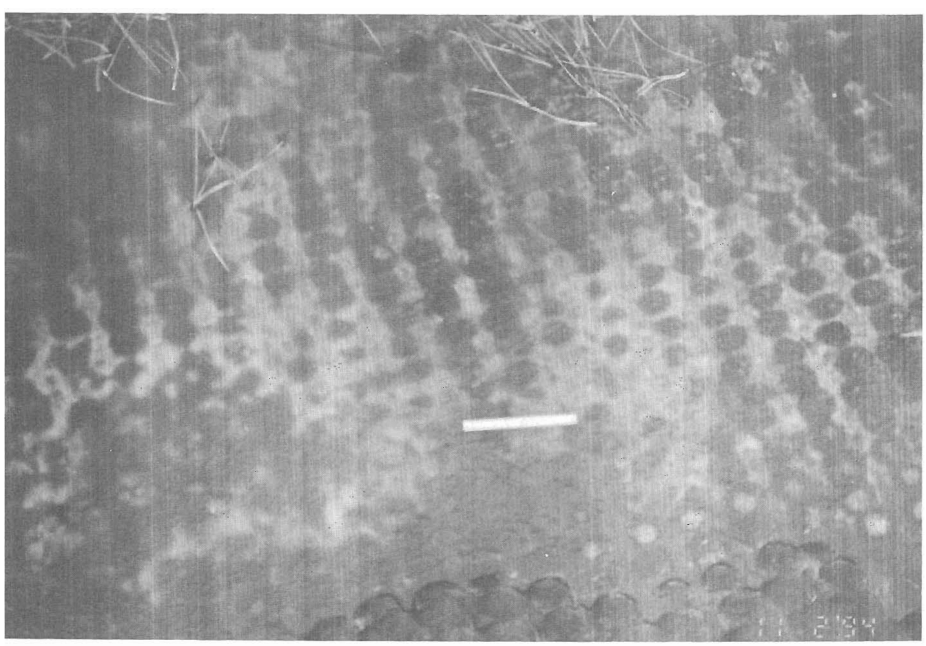


Photograph 69.—The outer fabric of the grout-filled mattress is beginning to deteriorate as was expected.

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

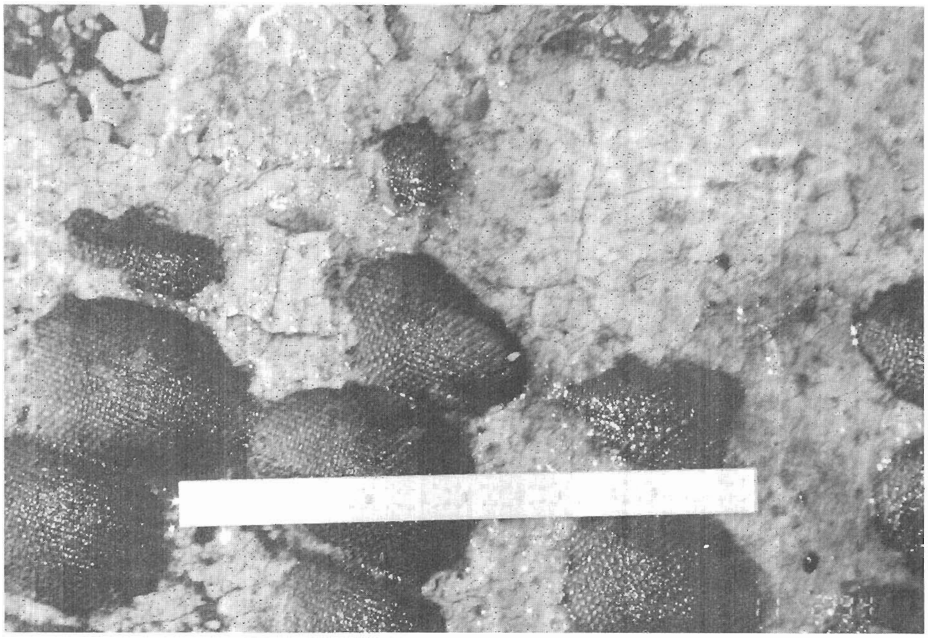


Photograph 70.—Above the waterline, the geotextile covering for the grout-filled mattress is very weak and can be easily torn by hand. Again, this deterioration was expected.



Photograph 71.—Small amount of cement paste between bricks in the invert.

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



Photograph 72.—Cement paste probably oozed through the outer geotextile during the grouting operation.

Test Section A-8.

Material: 3-inch grout-filled mattress

Description: The grout-filled mattress is Nicolon Armorform 3-inch USM

Construction Cost: $1.86 per square foot

Date Installed: November 1991 (first 200 feet) and November 1992 (500 additional feet) (59 and 47 months old)

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

Condition: Excellent - The grout-filled mattress is in excellent condition after 4 to 5 years of service, with no freeze/thaw damage. The first 200 feet with zippered seams has a much neater appearance than the second 500 feet with sewn seams. Both areas are uniformly grouted in spite of the uneven rocky subgrade. A small amount of cement paste is present in the invert between the concrete "bricks." No sediment or standing water is present in the invert suggesting higher velocities and a steeper slope through this test section. The slope visibly increases past the bridge (station 49+50). The grout-filled mattress is well tied-in to the bridge, with no gaps that would allow seepage. The outer fabric of the grout mattress is in good condition, with little deterioration, except for one location (station 54+50 left bank) where the geotextile has worn away, and several concrete "bricks" are missing. A subgrade rock (see photo 77) caused the grout mattress to be very thin at this location.

When the water is shut off in the fall, this test section only holds standing water for about 2 weeks, while Test Section A-7 holds standing water all winter. This side-by-side comparison demonstrates the higher seepage rate of the grout-filled mattress without a geomembrane underliner.

Maintenance: Minimal maintenance required to date

Performed: None

Needed: Need to patch the concrete mat at station 54+50.

Photographs: 73 through 78

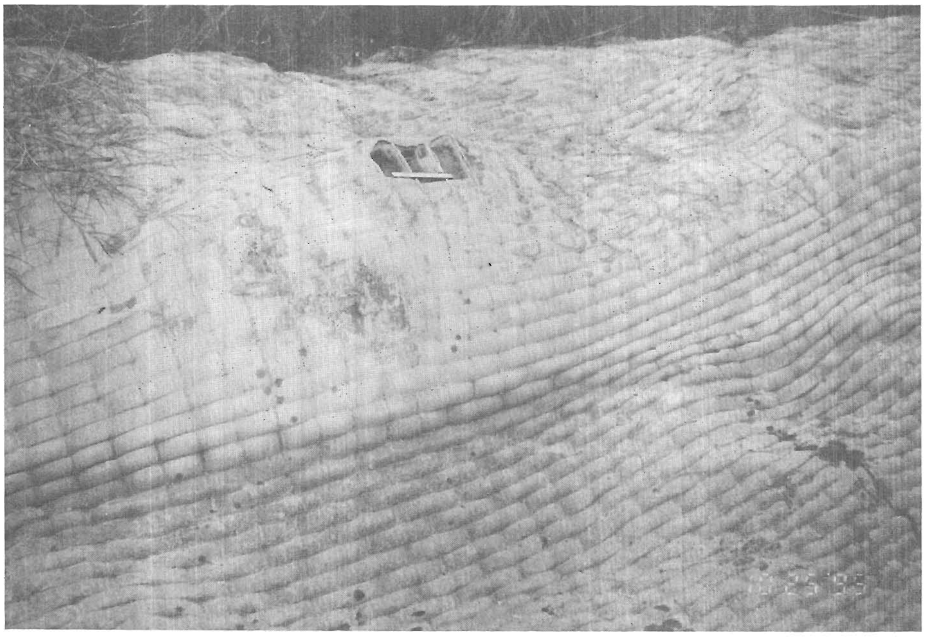
Arnold Canal - Test Section A-8
3-inch Grout-filled Mattress

Photograph 73.—Canal overview - excellent condition after 4 to 5 years of service.

Photograph 74.—The grout-filled mattress is well tied-in under the bridge.

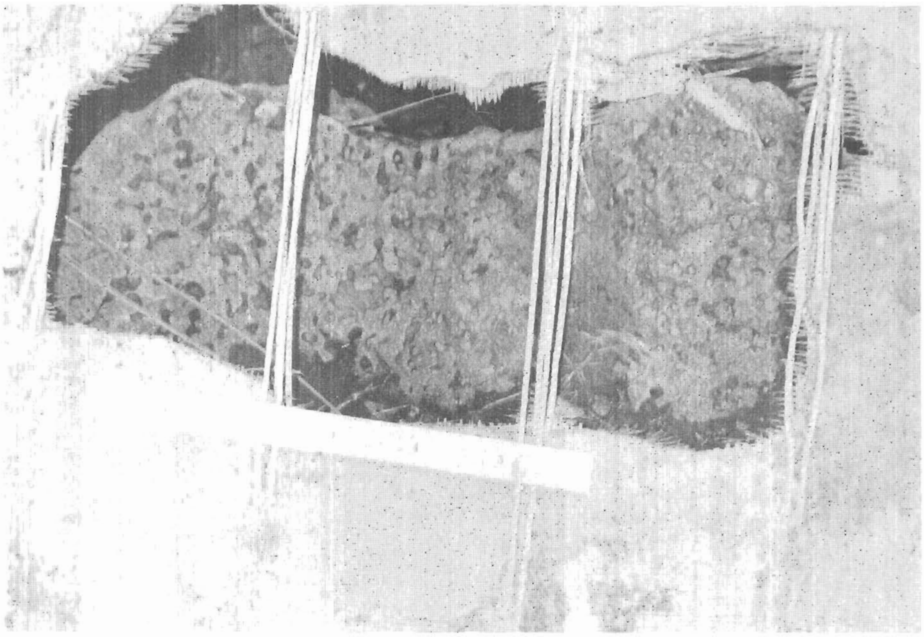
Arnold Canal - Test Section A-8
3-inch Grout-filled Mattress

Photograph 75.—Little sediment or standing water in this test section.

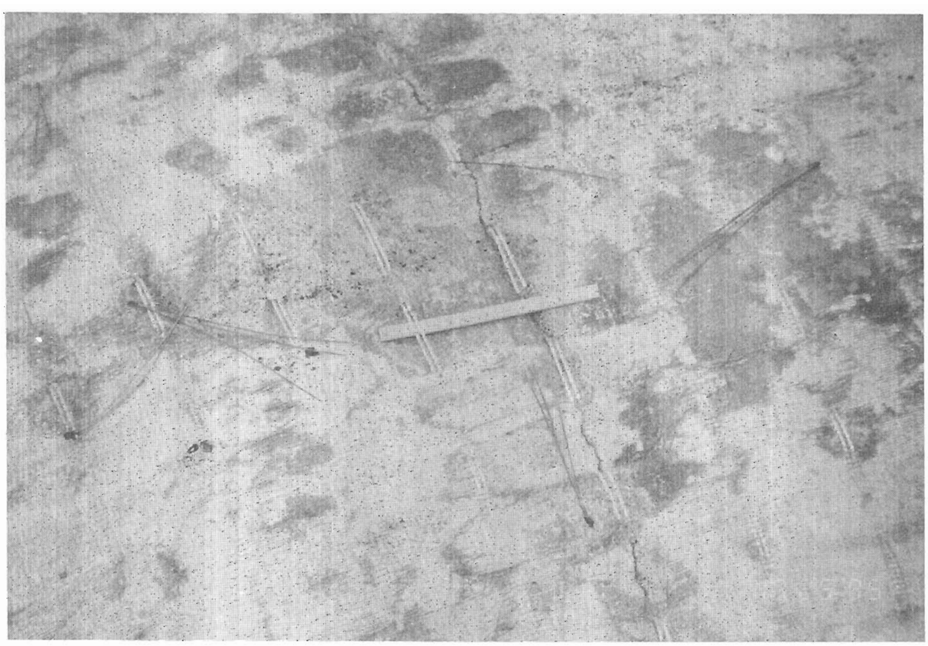


Photograph 76.—The grout-filled mattress has some minor damage at station 54+50.

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



Photograph 77.—Three "bricks" missing above the waterline at station 54+50. A subgrade rock is visible which caused the grout mattress to be very thin at this location.



Photograph 78.—Station 54+50 - Outer fabric has worn away.

Test Section A-9.—

Material:	60-mil VLDPE with 12-ounce geotextile cushion and 3-inch grout-filled mattress on side slopes only
Description:	The VLDPE is 60-mil Poly-America Dura-flex. The geotextile cushion is Amoco 4512 (12-ounce needle-punched, non-woven geotextile). The grout-filled mattress is Nicolon Armorform.
Construction Cost:	$1.79 per square foot
Date Installed:	November 1992 (removed from study after 28 months)
Location:	Station 55+00 to 65+00 (1,000 linear feet; 30,000 square feet)
Condition:	Removed from study after 28 months -

Several attempts were made to repair this test section. In December 1994, Polyflex and Canamer patched 20 to 30 holes, tears, and rips between stations 57+20 and 63+00. The holes and tears were from sharp subgrade rocks, and the cuts were attempts to deflate liner "whales." Snowy weather prevented them from completing the repairs. They also drilled several 1½-inch vent holes above the waterline in the grout-filled mattress to help vent any volcanic gases. The core holes were also used to confirm that the liner was properly installed and had not slipped down the side-wall bank. Five cores were drilled and all confirmed the proper location of the liner. One 6-inch diameter core was drilled to measure the thickness of the 3-inch grout-filled mattress. The core showed a nominal thickness of 2¼ inches with a minimum thickness of 1 inch and a maximum thickness of 3 inches.

In March 1995, Polyflex returned to seam the centerline cut from stations 63+00 to 65+00 and to patch an additional 40 to 50 holes and cuts and tears between stations 55+00 and 57+20. The downstream end (station 65+00) was to be left open (no anchor trench) to allow an escape route for any future "whales." Snowy weather prevented the completion of these repairs. Because the Arnold Irrigation District is committed to deliver stock water periodically during the winter, Arnold personnel requested the liner be removed. Reclamation agreed and directed Polyflex to cut out and completely remove the invert liner. The grout-filled mattress on the sideslopes was left in place. The subgrade beneath the geomembrane liner was very rocky with little bedding material. Much of the imported bedding material probably washed away during canal operation. There was no standing water except for one small pond at station 61+30. Unfortunately, the cause of the "whales" in Test Sections 9 and 10 was never resolved. Volcanic gases are suspected to be the cause.

No cement deposits remain in the Test Section 9 invert; a few piles are evident on the bank where they were deposited after removal. Many of the cement deposits appear to have been deposited in two lifts. The lower cement deposit contains black aggregate identical in appearance to the concrete cores taken from the grout-filled mattress. The upper deposit contains no aggregate and is believed to be cement paste that oozed through the fabric of the grout-filled mattress.

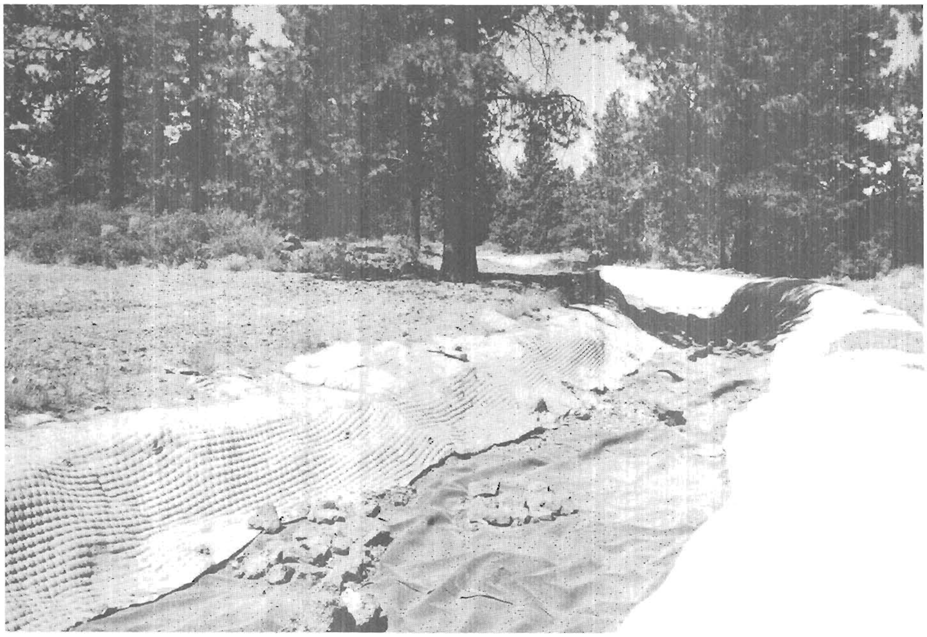
Maintenance: Extensive maintenance required to date

Performed: In 1994, Polyflex and Canamer repaired 20 to 30 small tears in test sections A-9 and A-10 (A-9 cost = $3,000), and the district placed concrete parking blocks and riprap over "whales" (A-9 cost = $3,000). The district also placed a concrete pad over the transition between Test Sections A-8 and A-9 at station 55+00 (since A-8 already has a concrete lining, full cost for A-9 = $240). In 1995, the contractor removed all the exposed geomembrane from the invert on test sections A-9 and A-10 (A-9 cost = $7,500).

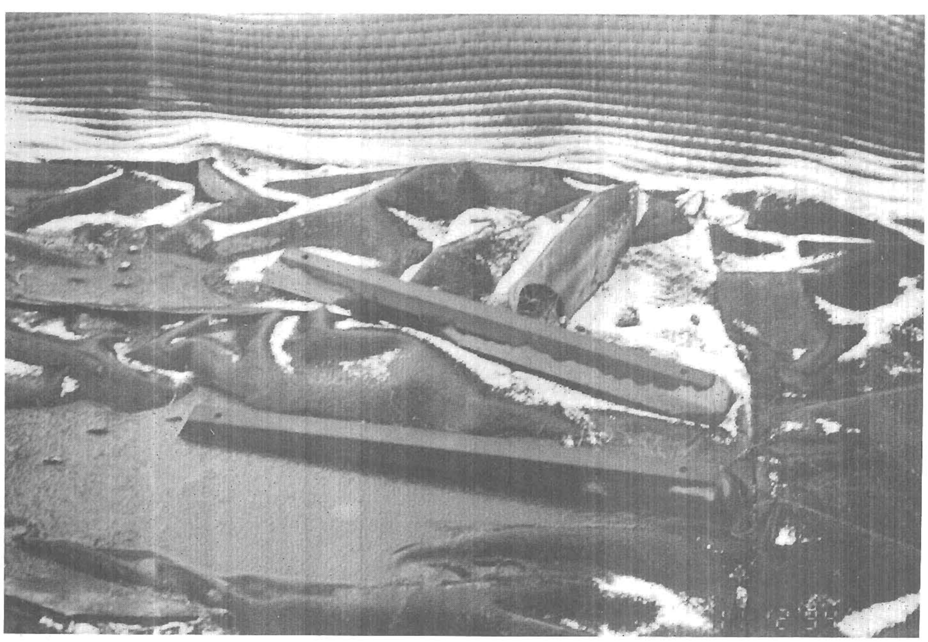
Needed: Test section abandoned.

Photographs: 79 through 88

Arnold Canal - Test Section A-9
60-mil VLDPE with 12-ounce geotextile cushion and 3-inch grout-filled mattress on side-slopes only



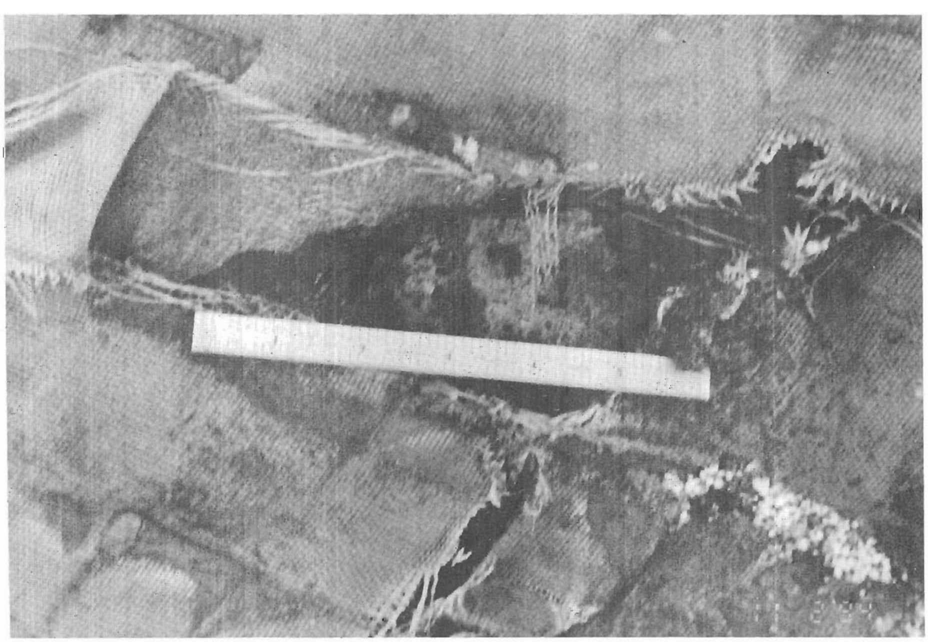
Photograph 79.—In 1993 and 1994, the irrigation district used rocks and concrete parking blocks to ballast the liner "whales" with little success.



Photograph 80.—Concrete parking blocks used as ballast.

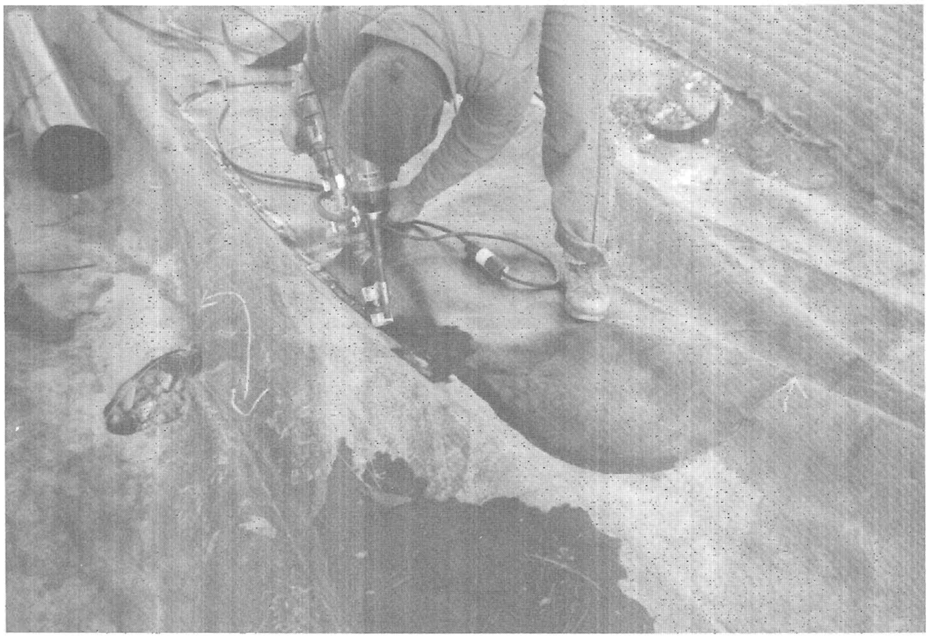
Arnold Canal - Test Section A-9
60-mil VLDPE with 12-ounce geotextile cushion and 3-inch grout-filled mattress on side-slopes only

Photograph 81.—Irrigation district installed a concrete patch at upstream transition to test section A-9.

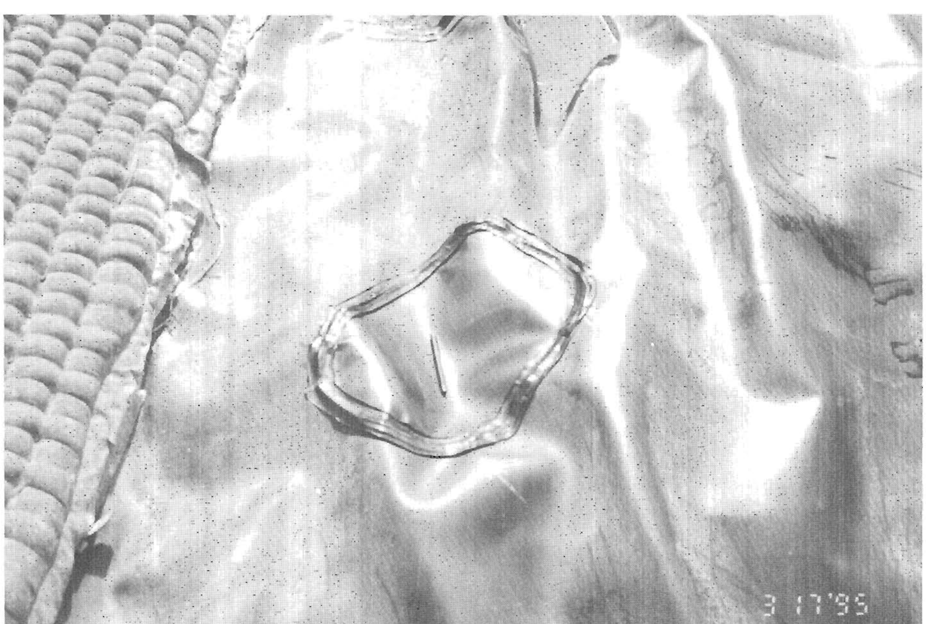


Photograph 82.—Grout-filled mattress is in good condition, with only isolated areas of minor damage.

Arnold Canal - Test Section A-9
60-mil VLDPE with 12-ounce geotextile cushion and 3-inch grout-filled mattress on side-slopes only

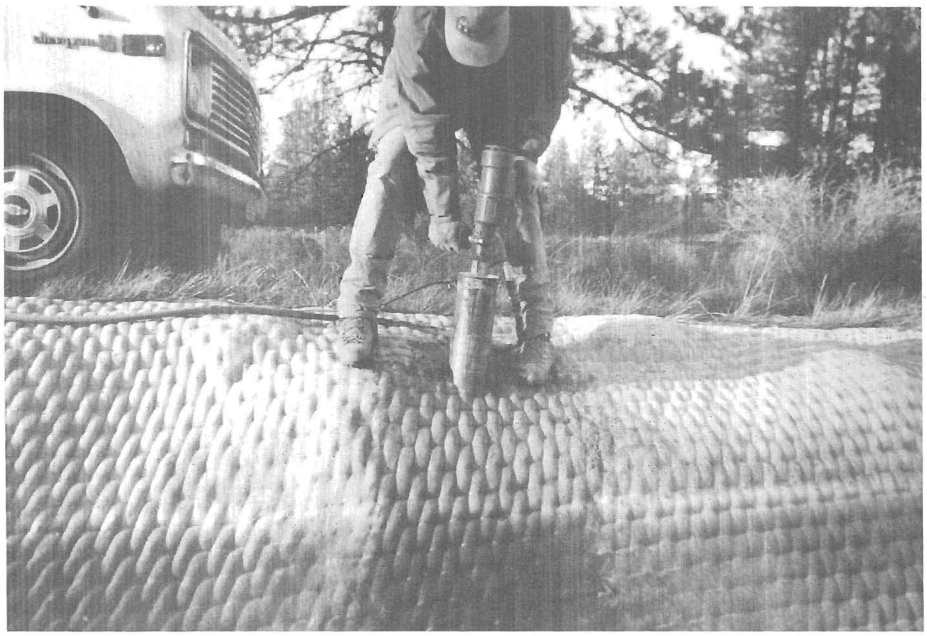


Photograph 83.—December 1994 - Contractor repairs geomembrane by grinding the VLDPE, tack-welding patch into position, and finally, attaching patch with extrusion welder.

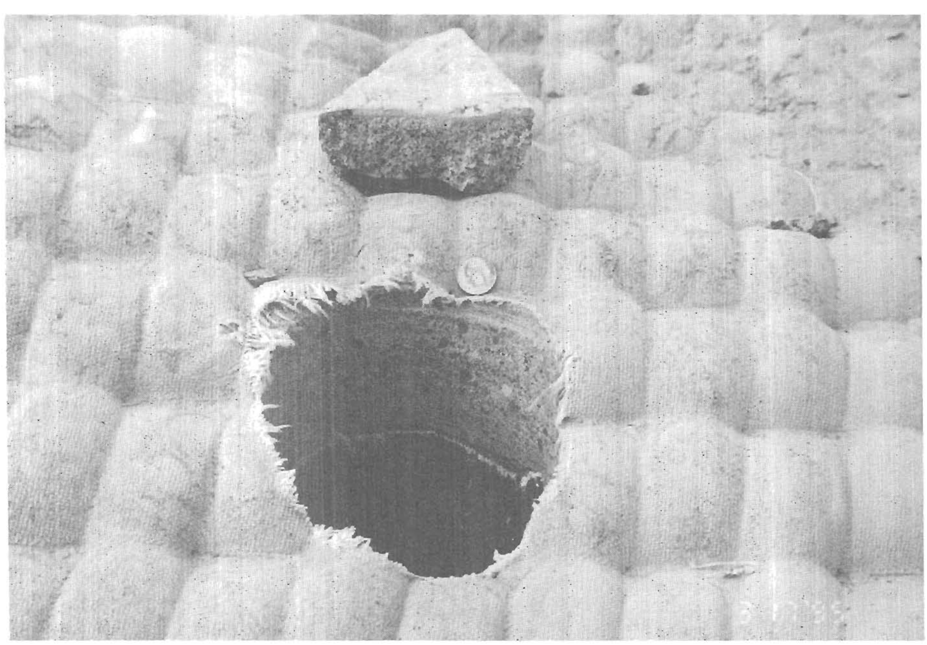


Photograph 84.—Finished patch.

Arnold Canal - Test Section A-9
60-mil VLDPE with 12-ounce geotextile cushion and 3-inch grout-filled mattress on side-slopes only



Photograph 85.—Contractor drills 6-inch diameter core to check thickness of grout-filled mattress. Contractor also drilled 1½-inch diameter holes to help vent volcanic gases.



Photograph 86.—Aggregate in grout-filled mattress appears identical to aggregate in cement deposits in canal invert.

Arnold Canal - Test Section A-9
60-mil VLDPE with 12-ounce geotextile cushion and 3-inch grout-filled mattress on side-slopes only

Photograph 87.—After 2 years of service, test section was in poor condition with numerous rips, tears, and cuts in the geomembrane.

Photograph 88.—Geomembrane liner removed from invert and test section abandoned after 2½ years of service.

Test Section A-10.—

Material:	60-mil HDPE with 12-ounce geotextile cushion and 3-inch grout-filled mattress on side slopes only.
Description:	The HDPE is 60-mil Poly-Flex. The geotextile cushion is Amoco 4512 (12-ounce needle-punched, non-woven geotextile). The grout-filled mattress is Nicolon Armorform.
Construction Cost:	$1.79 per square foot
Date Installed:	November 1992 (removed from study after 28 months)
Location:	Station 65+00 to 75+00 (1,000 linear feet, 30,000 square feet)
Condition:	Removed from study after 28 months

In March 1994, the irrigation district slit the HDPE down the centerline for the entire 1,000 linear feet to eliminate any further problems with liner "whales." Placement of a concrete pad over the invert was considered, but rejected because of limited funds. Instead the exposed HDPE was removed in March 1995, and this test section was abandoned. The grout-filled mattress on the side-slopes will be left in place. In many locations, the imported sand bedding had completely washed away, indicating there may have been significant flow beneath the liner.

There is no standing water in this test section, and a few "cement" deposits remain in the invert. Many piles of "cement" deposits are visible on the bank. Natural weathering is breaking down the deposits into very small pieces. Two types of deposits are present. Some of the deposits contain a black aggregate up to 1/4 inch diameter. These deposits with aggregate visibly match the concrete in the grout mattress in test section 7, 8, 9, and 10. These deposits appear to have been deposited first. On top of the "aggregate" deposit, is a layer of cement paste, ranging from ½ to 4 inches thick. These paste deposits are visibly similar to the thin paste observed between bricks on Test Sections 7 and 8. Both these deposits now appear to be from the grout-filled mattress used on Test Sections 7, 8, 9, and 10. Section 10 reportedly had 6 to 12 inches of standing water during construction. The "aggregate deposits" are believed to be excess cement grout that washed downstream to Test Section 10 during construction. The "cement paste" deposits probably oozed through the outer geotextile of the grout mattress and were then deposited downstream in Test Section 10.

Maintenance:	Extensive maintenance required to date

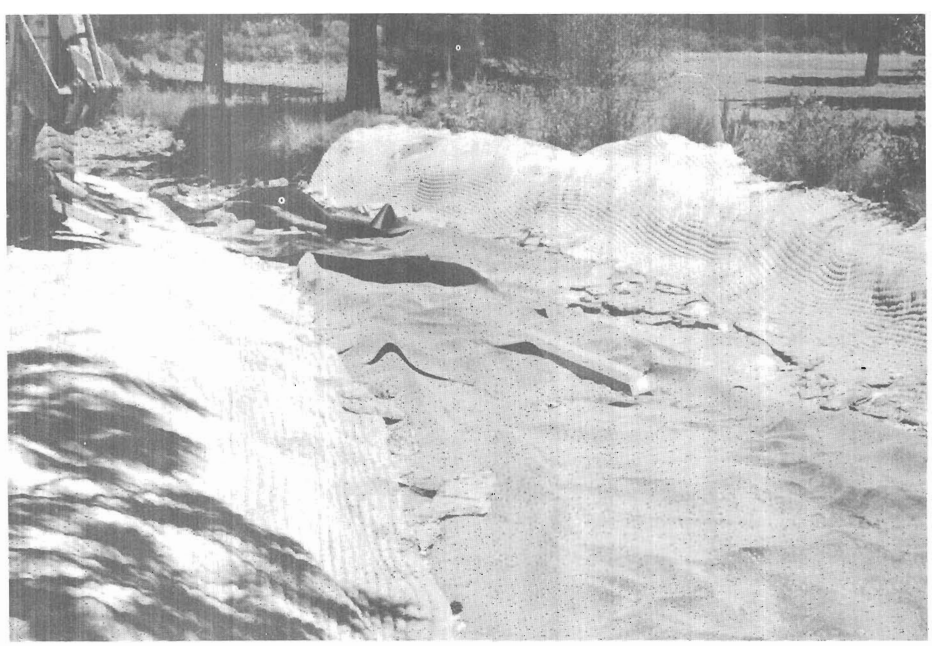
Performed: In previous years, the district removed Portland cement deposits from this test section (cost = \$320). In 1994, Polyflex and Canamer repaired 20 to 30 small tears in test sections A-9 and A-10 (A-10 cost = \$3,000), and the district placed concrete parking blocks and riprap over "whales" (A-10 cost = \$3,000). In 1995, the contractor removed all the exposed geomembrane from the invert on test sections A-9 and A-10 (A-10 cost = \$7,500).

Needed: Test section abandoned.

Photographs: 89 through 94

Arnold Canal - Test Section A-10
60-mil HDPE with 12-ounce geotextile cushion and 3-inch grout-filled mattress on side-slopes only

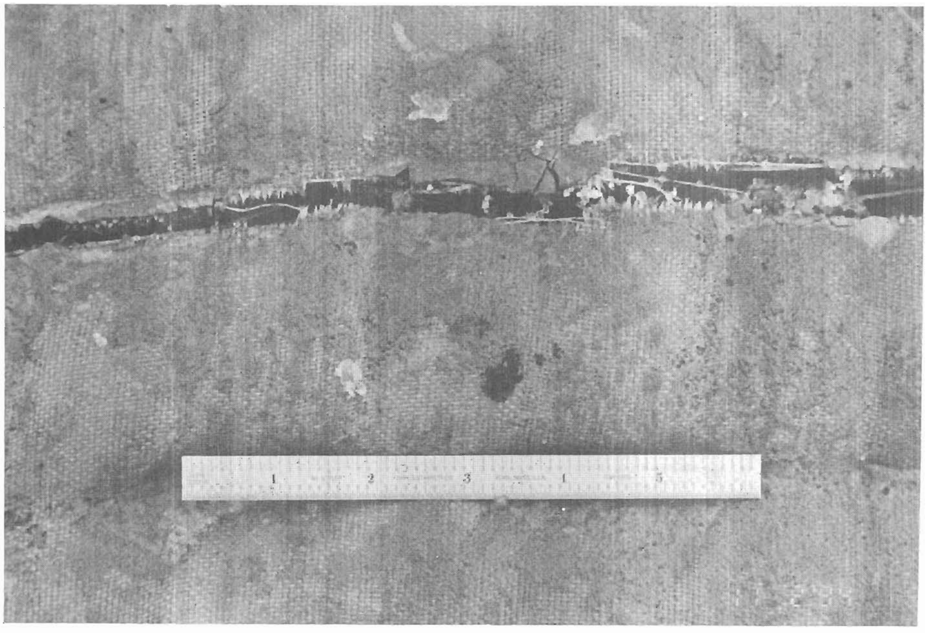
Photograph 89.—After 2 years of service, test section was in poor condition with numerous rips, tears, and cuts in the geomembrane.



Photograph 90.—Irrigation district used concrete parking blocks to ballast liner "whales," with little success.

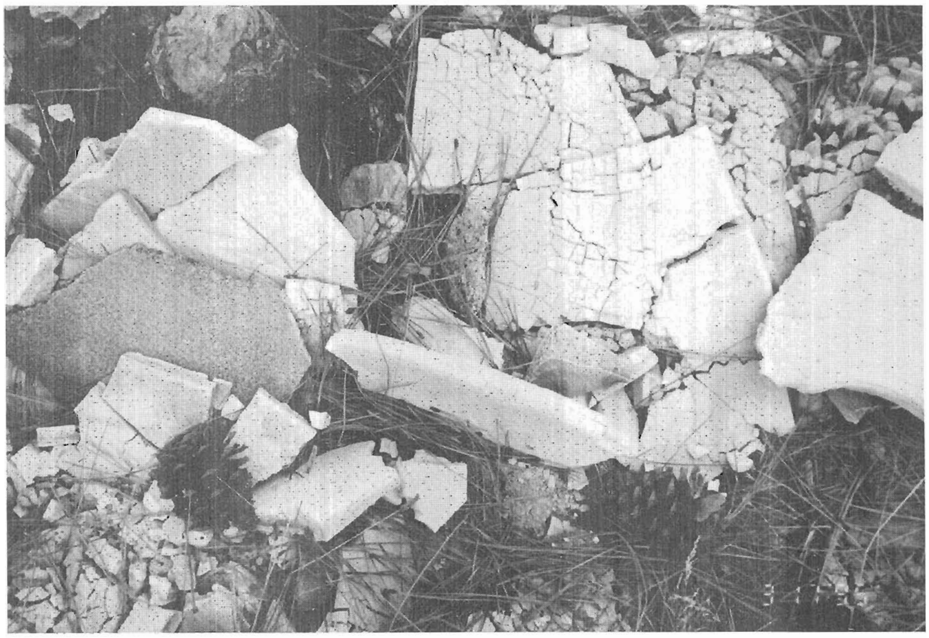
Arnold Canal - Test Section A-10
60-mil HDPE with 12-ounce geotextile cushion and 3-inch grout-filled mattress on side-slopes only

Photograph 91.—Test section removed from study after 2½ years of service. Geomembrane liner in the invert was removed in the Spring of 1995.

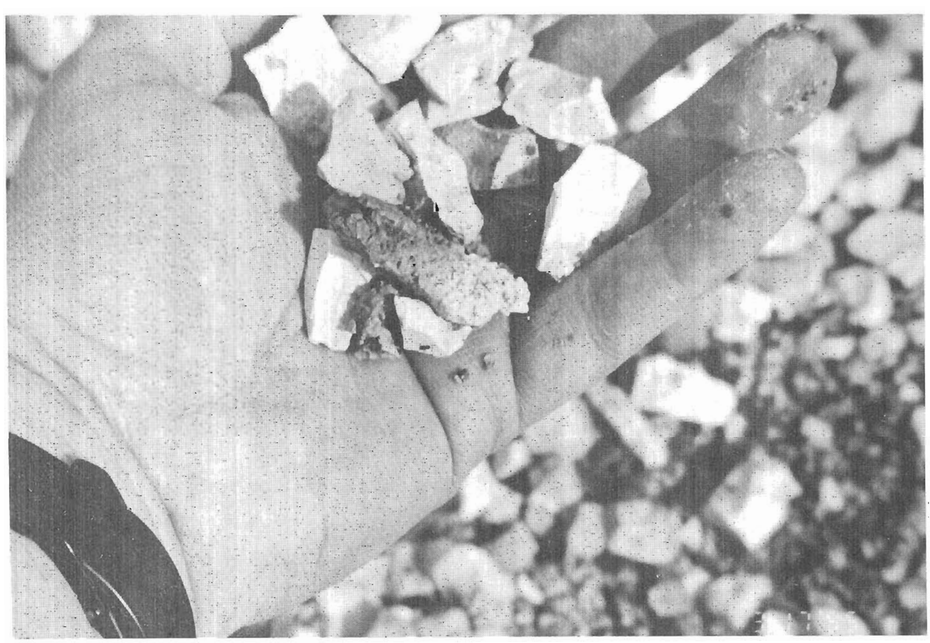


Photograph 92.—Grout-filled mattress is in good condition with only occasional minor damage, such as this longitudinal crack.

Arnold Canal - Test Section A-10
60-mil HDPE with 12-ounce geotextile cushion and 3-inch grout-filled mattress on side-slopes only



Photograph 93.—Extensive cement paste deposits found in test section A-10.



Photograph 94.—Natural weathering is rapidly breaking-down the cement-paste deposits.

North Unit Main Canal

Test Section N-1.—

Material:	SPF (Spray-applied Polyurethane Foam) with Futura 500/550 protective coating
Description:	SPF is 2 inches of 2-pound (lb/ft^3) foam covered with about ½ inch of 5-pound foam. Total protective coating thickness is 50 to 55 mils.
Construction Cost:	$4.33 per square foot
Date Installed:	October 1992 through March 1993 (48 months old)
Location:	Station -2+00 to 1+00 (300 linear feet, 18,000 square feet)

Condition:

Partially failed - About ⅓ of the invert foam (~ 3,000 square feet) has washed out just below the drop at the start of this test section. The washout initiated in the first few weeks of service (summer 1993) in the loose sand and gravel deposits (approximately station 0+00) that offered little uplift resistance to the buoyant foam. The high velocity water then undercut large, loose subgrade rocks, allowing more foam to break free. The washed-out foam was found 16 miles downstream at a siphon inlet. Some of the washed-out foam remained bonded to large rocks (6- to 12-inch diameter) and provided sufficient buoyancy to float the rocks downstream, as one cubic foot of 2-pound foam can float a 100-pound rock.

In addition to the washed-out foam, most of the remaining foam has lost its protective coating, including some loss of coating above the waterline. In total, about 50 percent of the side-wall foam and about 90 percent of the invert foam has lost its protective coating. Poor bond between the foam and the tan base coat was anticipated because the foam was installed in October 1992, but bad weather delayed application of the protective coating until March 1993. The bond appears good between the tan base coat and white topcoat. The exposed foam is weathering quickly, ranging in color from dark brown to deep orange. In a few areas (less than 1,000 square feet), the 5-pound top-foam has delaminated from the 2-pound base foam. Deterioration is expected to accelerate in the future.

Maintenance:

Extensive maintenance required to date

Performed: No maintenance in 1994, 1995, or 1996

In previous years, the irrigation district removed washed-out foam from the siphon inlet (N-1 cost = $1,387) and installed a trash/weed rack at the siphon (N-1 cost = $240), total cost = $1,627.

Needed: None - Extensive repairs to foam and coating are needed. However, repaired foam will probably also wash out. Therefore, no repairs are planned at this time. Instead, this test section will only be monitored for additional failures. If repairs were to be performed, the irrigation district would need spray foam equipment, spray foam, protective coatings, and specialized training.

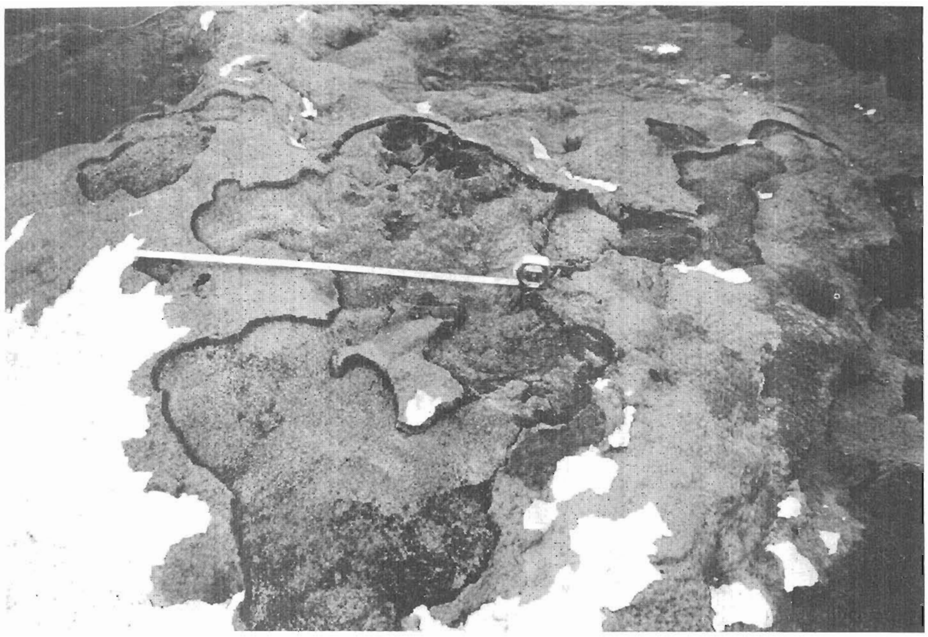
Photographs: 95 through 98

North Unit Canal - Test Section N-1
SPF with Futura 500/550 protective coating

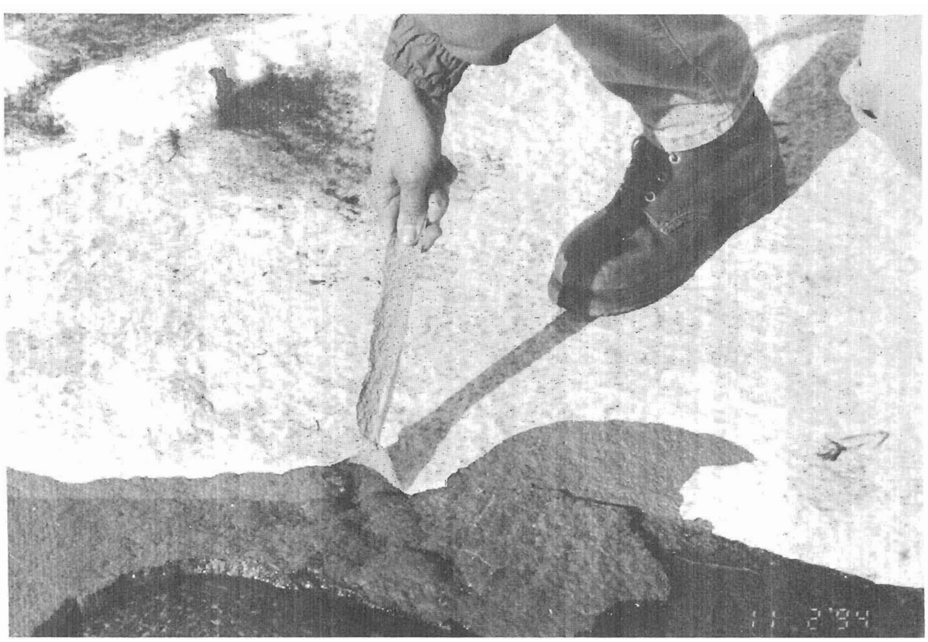
Photograph 95.—Canal overview - poor condition (partially failed) after 4 years of service. About 90% of the coating is missing and about 20% of the foam has been washed out.

Photograph 96.—Typical subgrade conditions beneath the foam.

North Unit Canal - Test Section N-1
SPF with Futura 500/550 protective coating



Photograph 97.—In small areas, the 5-pound foam top foam has disbonded and washed away, exposing the underlying 2-pound base foam.

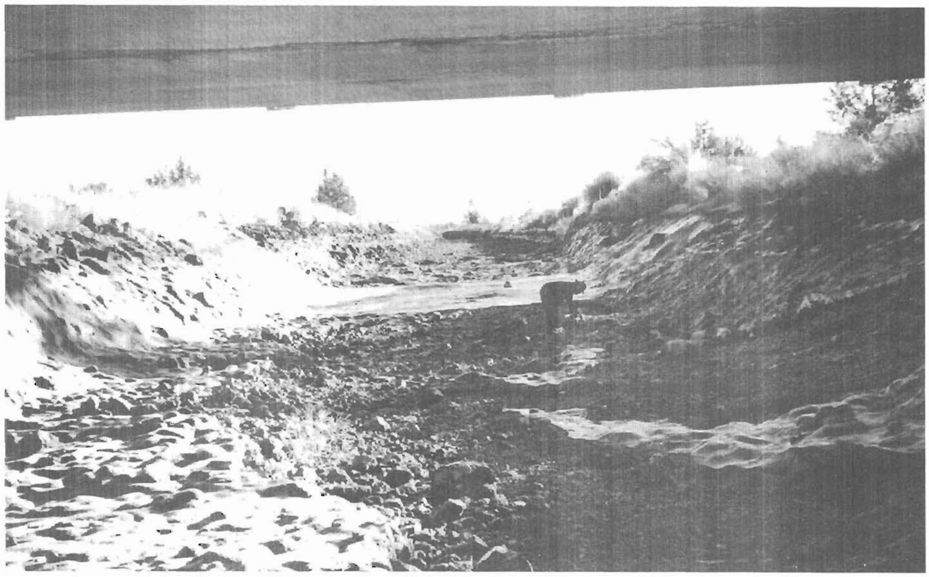


Photograph 98.—The remaining protective coating is poorly bonded and shows signs of deterioration.

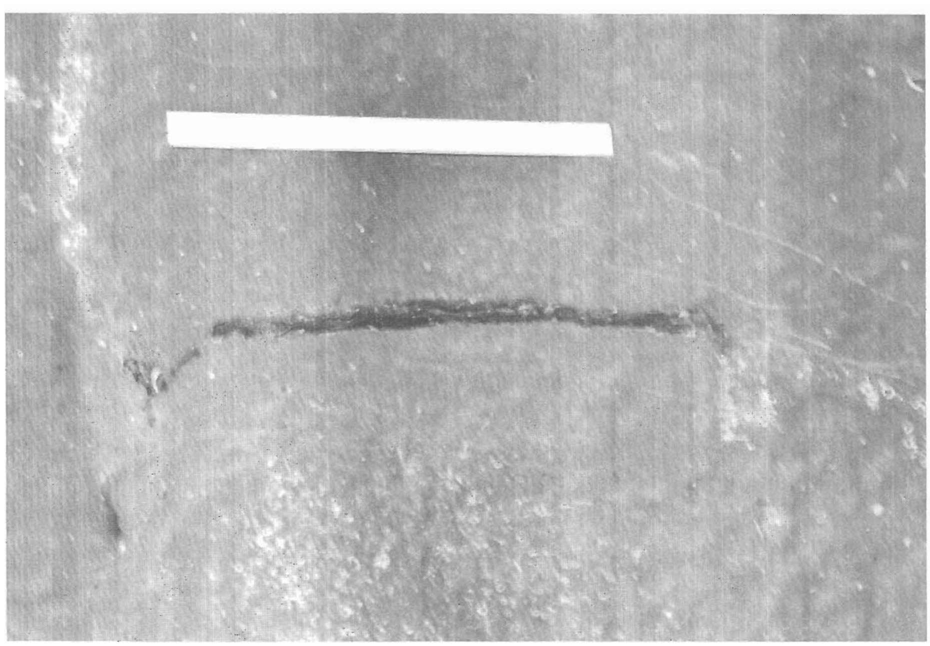
Test Section N-2.—

Material:	SPF with Geothane 5020 protective coating.
Description:	SPF is 2 inches of 2-pound foam covered with ½ inch of 5-pound foam. Total protective coating thickness is 50 to 60 mils.
Construction Cost:	$3.92 per square foot
Date Installed:	October 1992 (48 months old)
Location:	Station 1+00 to 4+00 (300 linear feet; 18,000 square feet)
Condition:	Partially failed - About half (4,000 ft^2) of the invert foam is missing. The foam washout started in an area of loose sand and gravel in Test Section 1 in the first few weeks of service (summer 1993). The foam failure propagated downstream into Test Section 2, stopping where the foam is bonded to a solid concrete slab crossing the canal (buried pipe crossing). A small amount (10 percent) of the remaining invert foam has lost its protective coating. On the sideslopes, very little of the foam has lost its protective coating. Above the waterline, the foam and coating are intact. The coating shows moderate degradation on the south-facing sideslope and only minor degradation on the north-facing sideslope. Overall, the coating is in far better condition than on Test Section 1. Finally, a few cracks have developed in the foam downstream of the concrete apron. These cracks measure up to 8 inches long and extend completely through the foam and coating.
Maintenance:	Extensive maintenance required to date Performed: No maintenance in 1994, 1995, or 1996 In previous years, the district removed washed-out foam from siphon inlet (N-2 cost = $1,387). Installed weed rack at siphon (N-2 = $240). Total cost = $1,627. Needed: None - No repairs are planned - extensive repairs to foam and coating are needed, but repaired foam would probably also wash out. Therefore, this test section will only be monitored for additional failures. If repairs were to be performed, the irrigation district would need spray foam equipment, spray foam material, protective coatings, and specialized training.
Photographs:	99 through 102

North Unit Canal - Test Section N-2
SPF with Geothane 5020 protective coating.

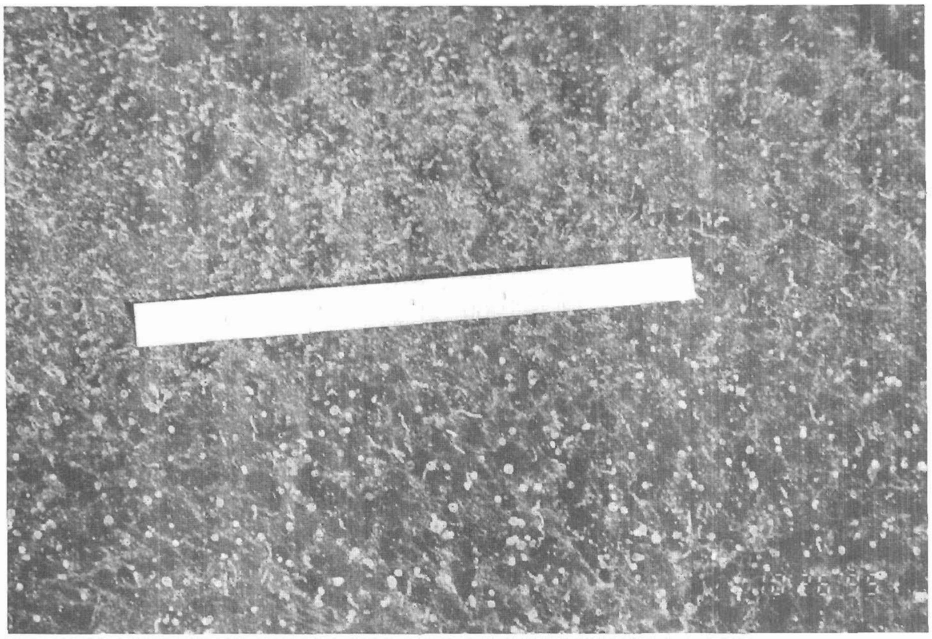


Photograph 99.—Canal overview - poor condition (partially failed) after 4 years of service.

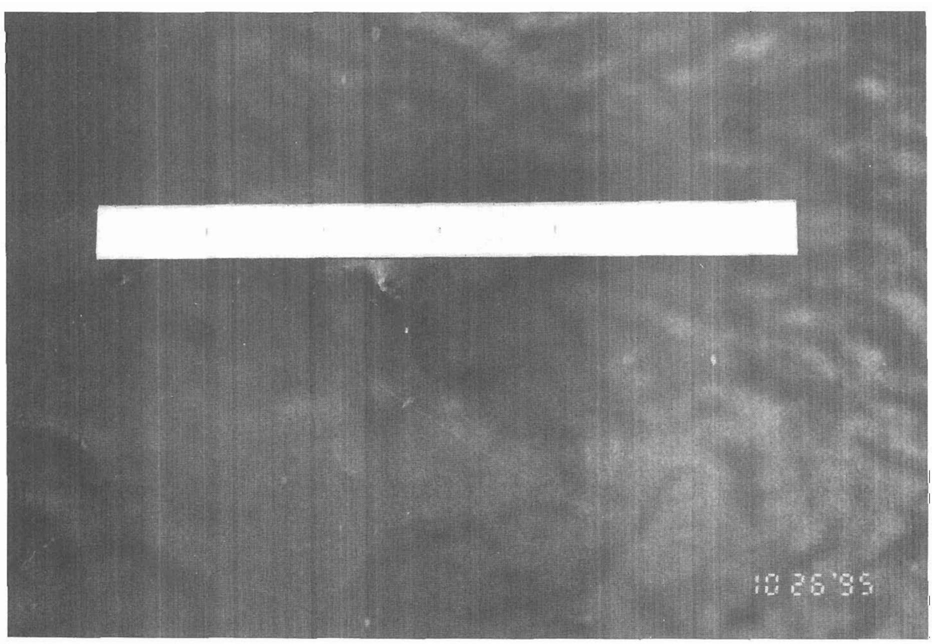


Photograph 100.—Crack is approximately 8 inches long and extends completely through the foam.

North Unit Canal - Test Section N-2
SPF with Geothane 5020 protective coating.



Photograph 101.—Protective coating on the north bank (south-facing) is showing moderate degradation.



Photograph 102.—Protective coating on the south bank (north-facing) is showing only minor degradation.

Test Sections N-3 and N-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 non-woven geotextile. Total protective coating thickness is 60 mils.
Construction Cost:	$2.64 per square foot
Date Installed:	October 1992 (complete failure after first filling - 7 months old)
Location:	Station 4+00 to 7+00 (300 linear feet; 18,000 square feet) Station 7+00 to 10+00 (300 linear feet; 18,000 square feet)
Condition:	Complete failure - Sections of the geotextile liners washed out the first time the canal was filled with water (May 1993). The geotextiles tore at the foam anchor trench, and several large sections of geotextile washed downstream, damaging a pipeline crossing. The irrigation district removed all remaining liner in these two test sections. See the "2-Year Durability Report" for further details.
Maintenance:	Extensive repairs required to date

Performed: No maintenance performed in 1994, 1995, or 1996

April 1993 - patched numerous rips on side slopes and in invert over large angular rocks. Also, some seams had very poor bond and were repaired. One 20-foot section of seam had essentially zero bond. The water district repaired rips with geotextile or fiberglass patches and a Geothane 520 (cold-applied version of Geothane 5020). The large unbonded seam was repaired with a 20-foot by 3-foot concrete cap. The cost was $555 for each test section.

May 1993 - The irrigation district removed all remaining geotextile liners (cost = $1,387 each), and repaired the damaged pipeline crossing (cost = $ 803 per test section)

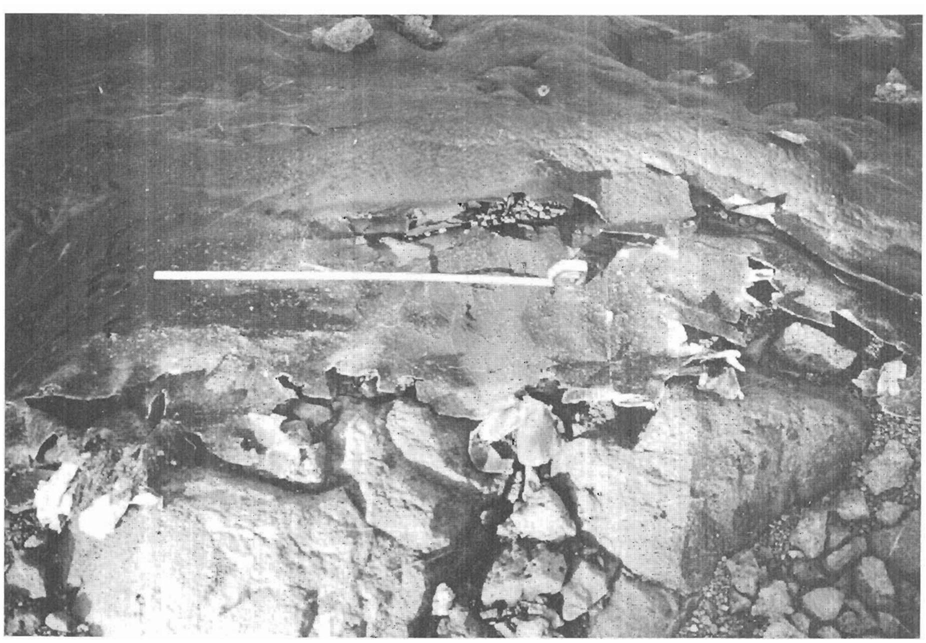
Total maintenance costs = $2,745 for each test section

Needed: None - Test sections abandoned

Photographs: 103 and 104

North Unit Canal - Test Sections N-3 and N-4
Geotextile with spray-applied Geothane 5020 membrane

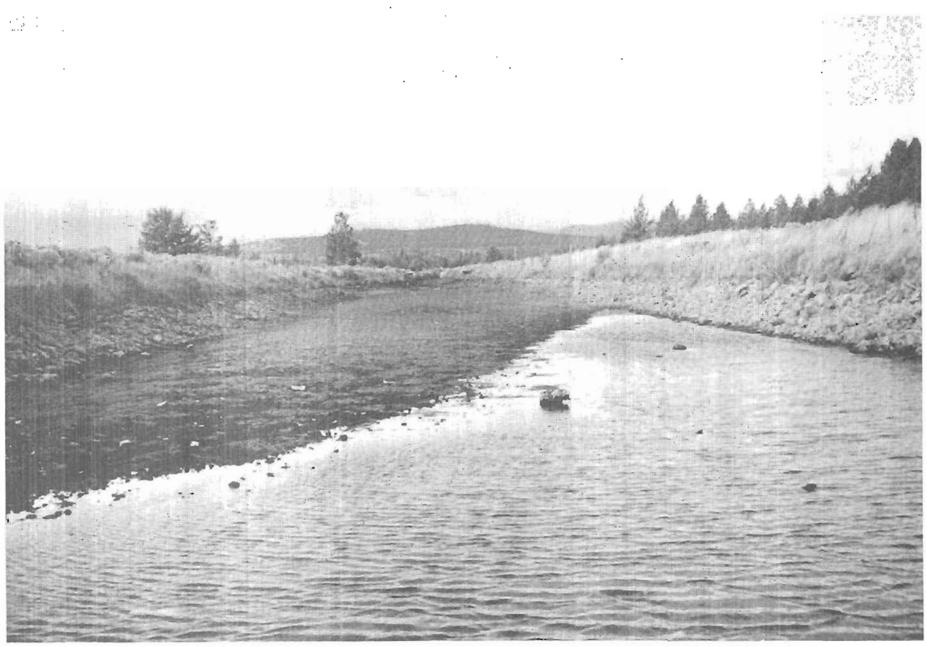
Photograph 103.—The foam anchor trench is all that remains of Test Sections N-3 and N-4.



Photograph 104.—Remnants of foam cut off trench at the upstream end of Test Section N-3.

Test Section N-5.—

The material for this test section has not yet been determined. Photograph 105 shows the existing subgrade condition with extensive silt deposits in the invert.



Photograph 105.—Future site for Test Section N-5.

Test Sections N-6 through N-9.— General comments apply to all 4 shotcrete sections:

Material:	3-inch shotcrete
Date Installed:	February 1992 (56 months old)
Condition:	Excellent - All the shotcrete is in excellent condition. In fact, the district is so pleased with the performance and water savings of these shotcrete test sections that they are contracting to line an additional 12 miles of this canal with roller compacted concrete beginning in 1997.

No visible differences exist in the performance of the four shotcrete test sections. No freeze/thaw damage is evident after 4½ years of service. A large pond just upstream from the drop structure (station 27+80) indicates a low seepage rate. Small ponds are typically present on all four test sections, even several weeks after water turn off. See the Seepage Chapter for results of the November 1994 ponding tests.

Contraction cracks on the side walls have developed every 100 to 200 feet. Crack width varies from hairline to 1/8 inch. None of the cracks extend completely across the canal prism. Instead, the cracks disappear somewhere in the side wall or invert. Cracks are more evident during cold weather.

Also, some small irregular voids (holes) up to 8 inches in depth were found in the shotcrete. Several partially exposed rocks were discovered with little to no shotcrete cover.

The thickness of the shotcrete is variable because of normal problems with field installation quality control. A couple of holes developed and were patched. At these locations, the shotcrete was found to be very thin (less than 1 inch). As further cracks or holes develop, the shotcrete thickness will be measured and compared to the degree of cracking and deterioration.

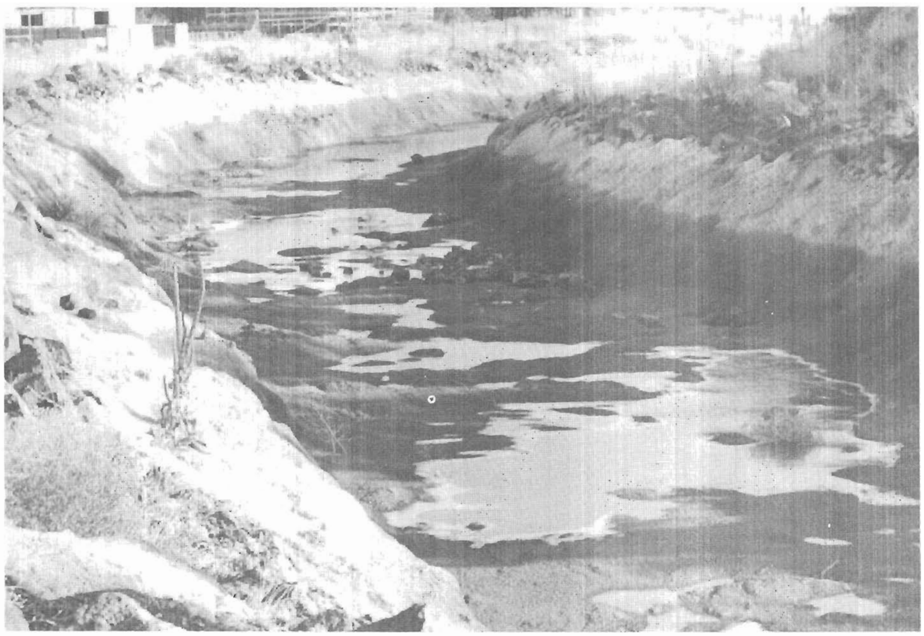
The areas where the flow prism is constricted and where the velocity increases show a small amount of exposed aggregate in the invert caused by erosion of the surface cement. This abrasion does not appear to be severe.

Many large rocks (typically 12 inches in diameter) are collecting in the canal invert (perhaps rolled in by local youths). Grafitti is visible in two or three locations.

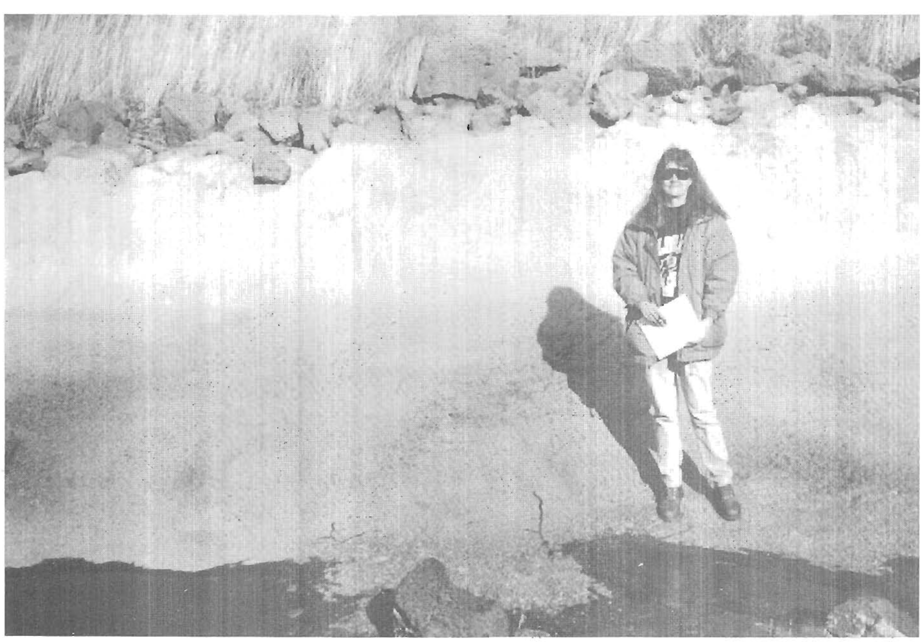
Vegetation is growing out of cracks in the shotcrete near the top of side slopes and even in some isolated sediment deposits in the canal invert. A thin layer of algae is present throughout the shotcrete test sections.

Photographs: 106 through 115

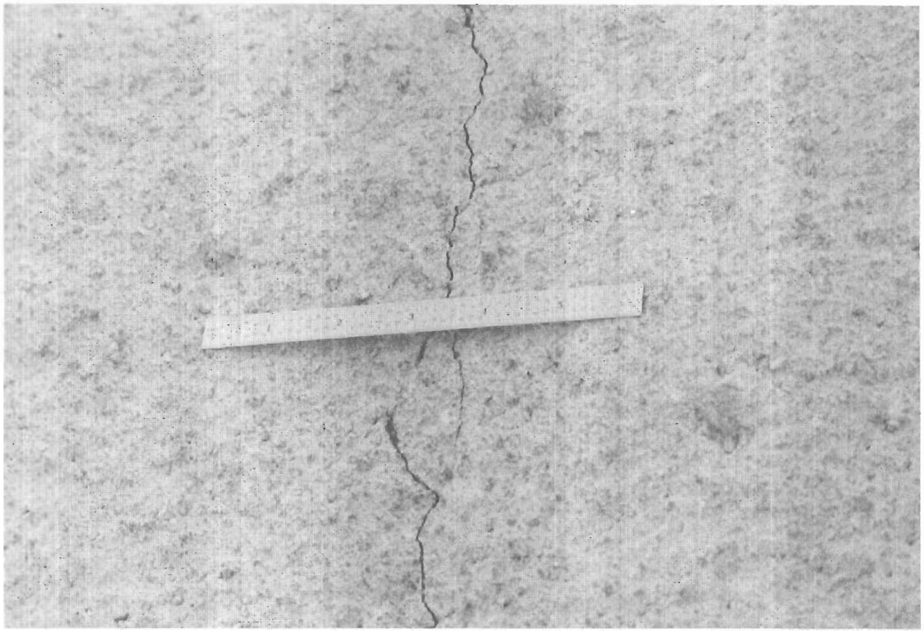
North Unit Canal - Test Sections N-6, N-7, N-8 & N-9
3-inch shotcrete



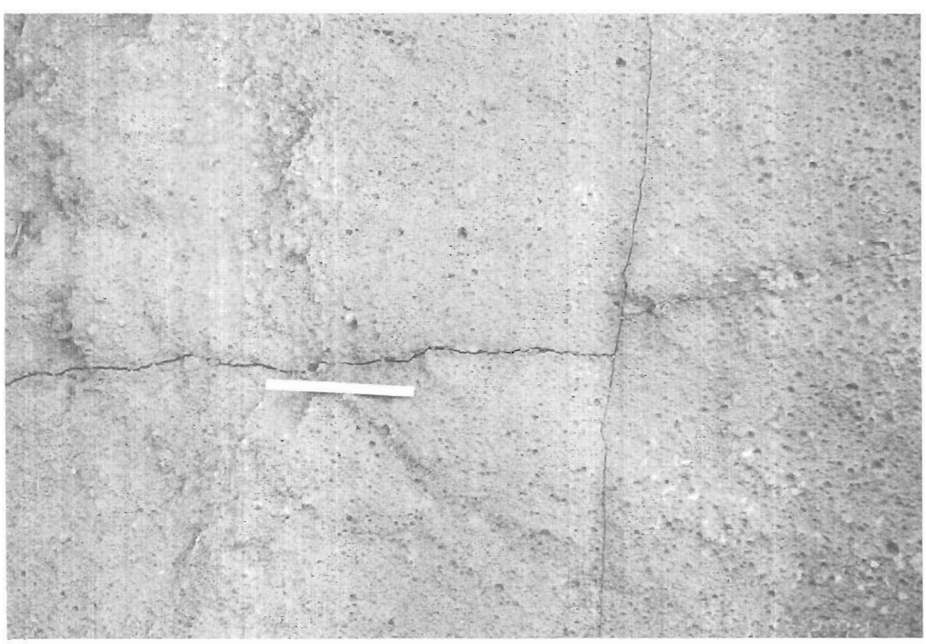
Photograph 106.—Canal overview - shotcrete test sections are in excellent condition after 4½ years service.



Photograph 107.—Typical transverse contraction crack which starts on the sideslope and then disappears somewhere in the invert.

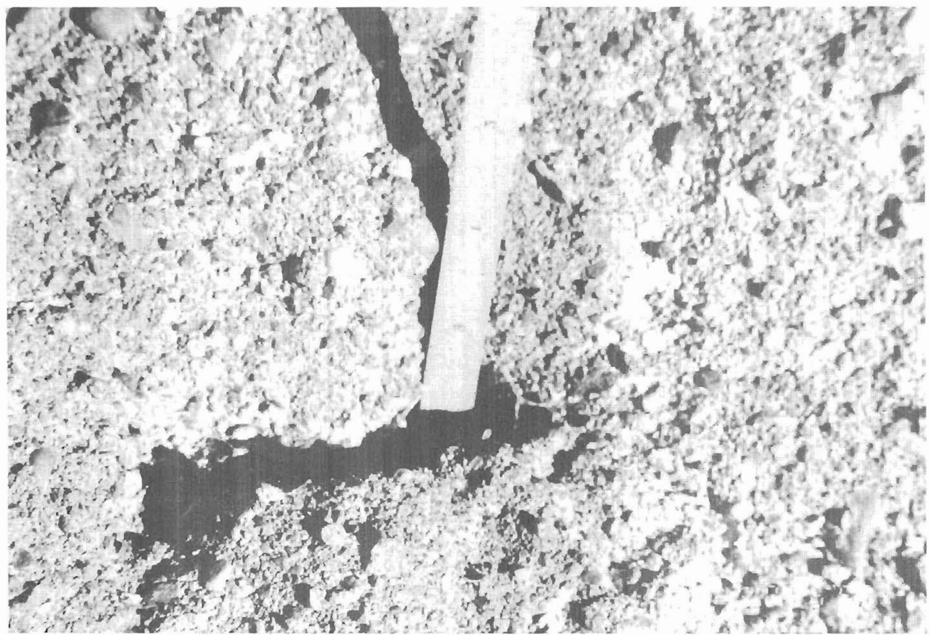


Photograph 108.—Crack widths range from hairline to 1/8 inch.

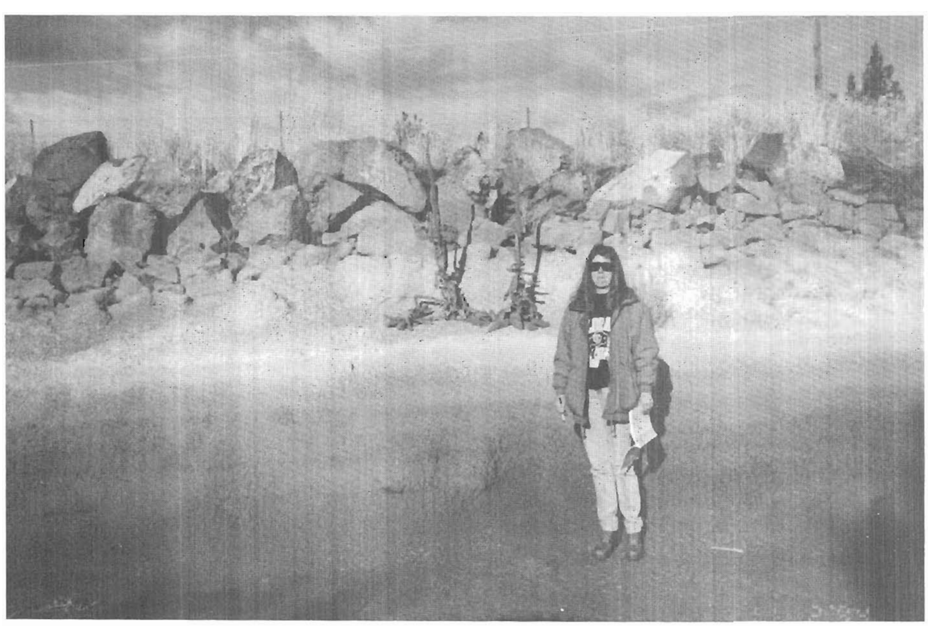


Photograph 109.—A couple of longitudinal cracks have developed in the side walls.

North Unit Canal - Test Sections N-6, N-7, N-8 & N-9
3-inch shotcrete



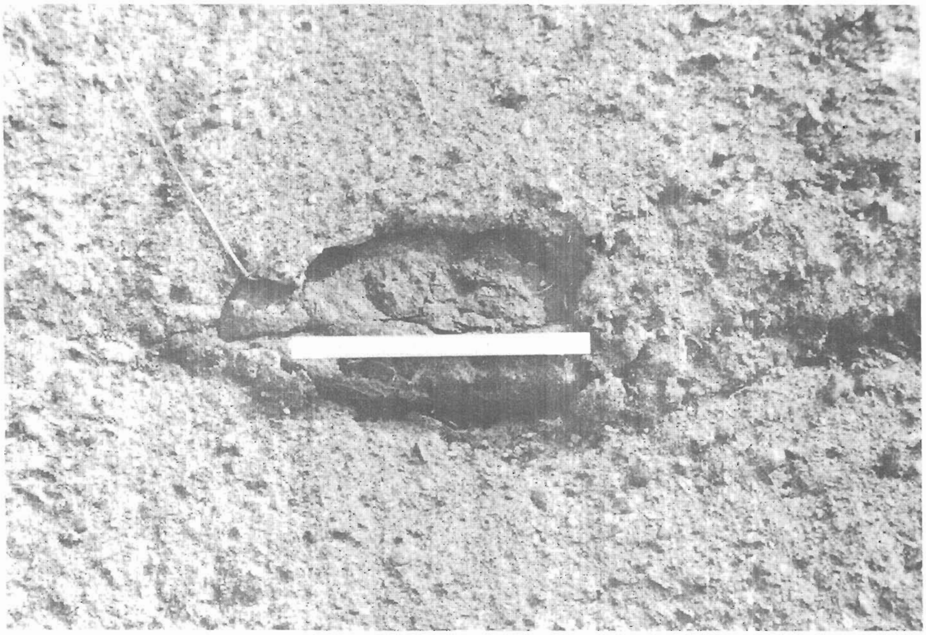
Photograph 110.—Many small voids have developed in the shotcrete.



Photograph 111.—Vegetation growing at top of side wall.

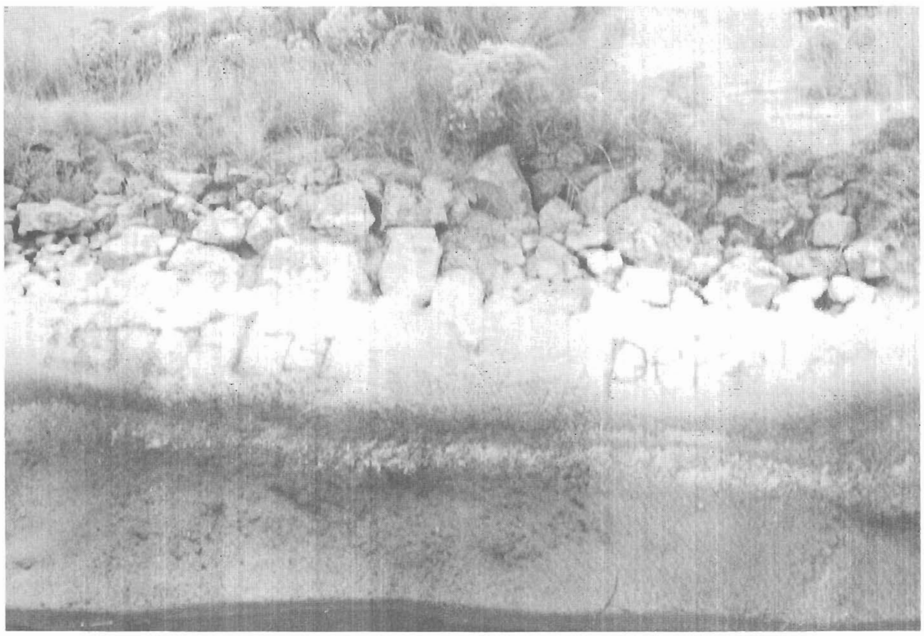
North Unit Canal - Test Sections N-6, N-7, N-8 & N-9
3-inch shotcrete

Photograph 112.—Installation contractor's thickness probe for assuring 3-inch shotcrete thickness.

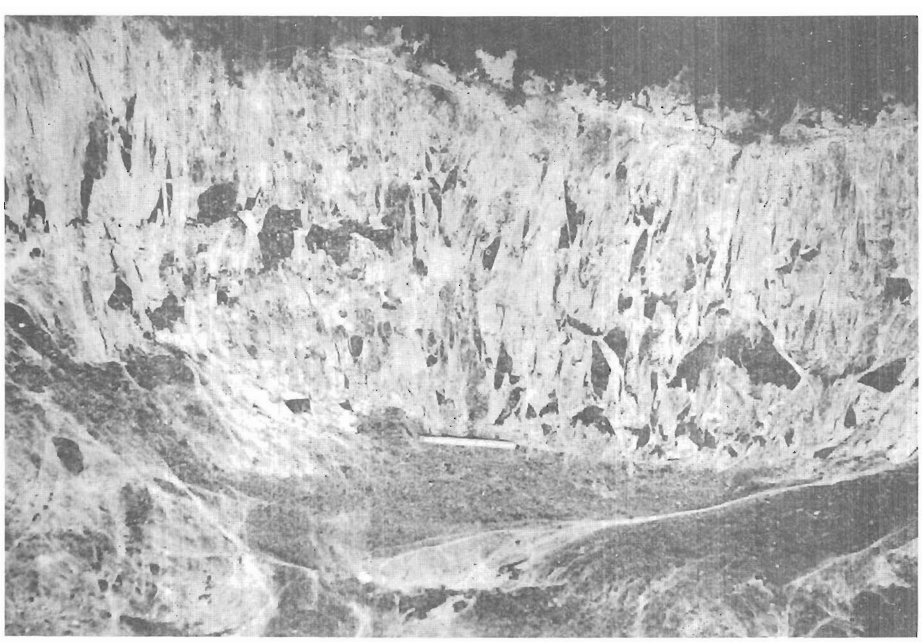


Photograph 113.—Exposed subgrade rock with little to no shotcrete cover.

North Unit Canal - Test Sections N-6, N-7, N-8, and N-9
3-inch shotcrete



Photograph 114.—Graffiti has appeared in two or three locations on the shotcrete test sections.



Photograph 115.—A thin layer of algae has grown throughout the shotcrete test sections.

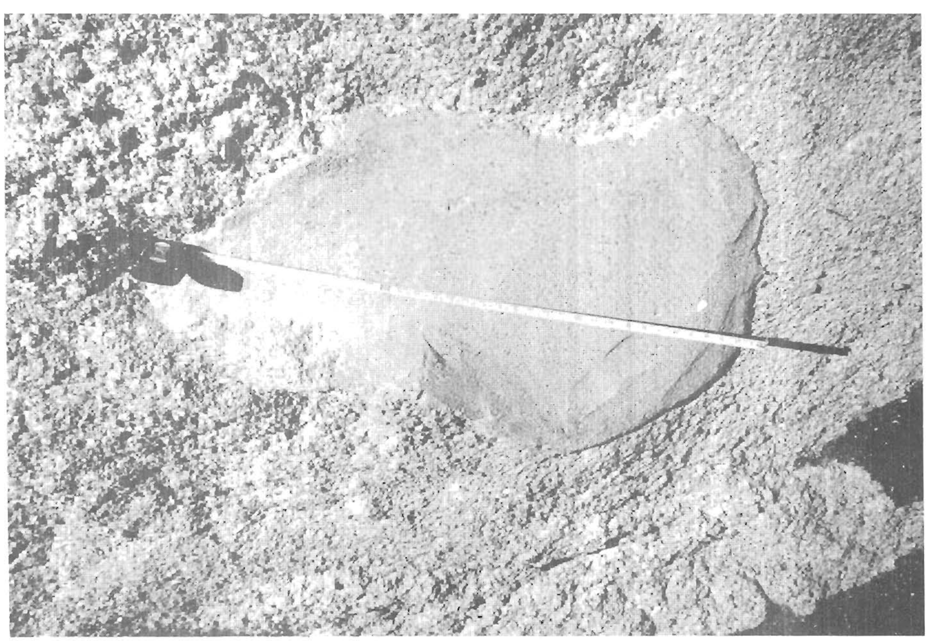
Test Section N-6.—

Material:	3-inch shotcrete reinforced with Novocon steel fibers
Description:	Steel fibers are 1½-inch Novocon crimped fibers (Novocrimp)
Construction Cost:	\$1.59 at a fiber dosage of 50 lb/yd^3 \$1.44 at a fiber dosage of 25 lb/yd^3
Date Installed:	February 1992 (56 months old)
Location:	Station 20+00 to 25+00 (500 linear feet, 30,000 square feet)
Condition:	Excellent - Shotcrete performing well after 4½ years of service. This test section has some cracking, voids, exposed subgrade rocks, and vegetation typical of all the shotcrete test sections. On the left bank (on this test section only) the contractor brought in soil to fill voids in the irregular subgrade before shotcreting. However, the imported silty material washed out during shotcreting, resulting in some voids under the shotcrete surface. A couple of 1- to 2-foot-diameter holes developed in the shotcrete. In both cases, the shotcrete was found to be only about one inch thick. Additional holes may appear where the shotcrete is thin and not well supported over voids in the subgrade. Steel fibers visible on the shotcrete surface are corroded, rust-brown in color, and very weak (break easily when bent 180 degrees by hand). However, steel fibers within the shotcrete are shiny bright and show no sign of corrosion. No visible differences were noted between the first 250-foot section containing 50 pounds of steel fibers per cubic yard of shotcrete and the second 250-foot section with 25 lb/yd^3. A ponding test was performed in November 1994 on this test section (See Seepage Chapter).
Maintenance:	Minimal maintenance required to date Performed: In previous years, the district patched two holes in the shotcrete and removed some large boulders (cost = \$977). In 1994, before the ponding test, the district performed some minor repairs, consisting primarily of sealing about 60 feet of transverse cracks with elastomeric sealant (cost = \$120). District also patched a few small holes in shotcrete. Holes were typically 6-inch diameter or less (cost = \$100).

	Needed:	None
Photographs:	116 through 121	

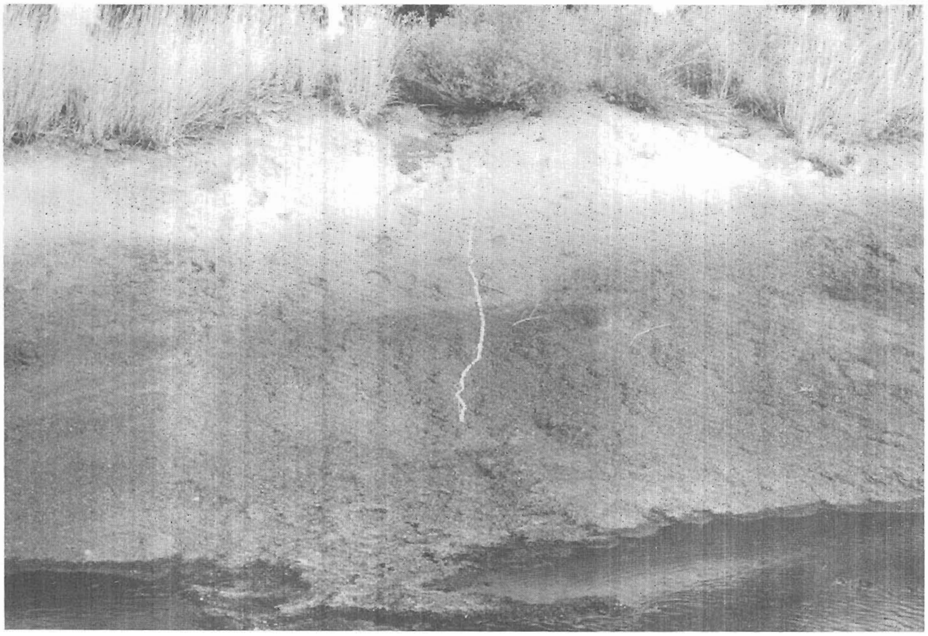
North Unit Canal - Test Section N-6
3-inch shotcrete reinforced with Novocon steel fibers

Photograph 116.—Canal overview - excellent condition after 4½ years of service.

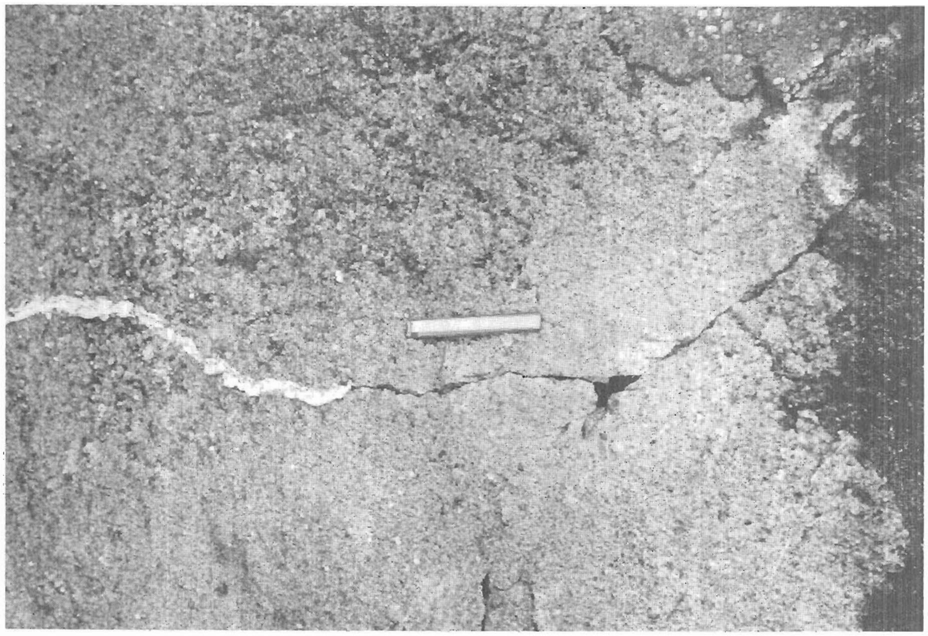


Photograph 117.—Two-foot diameter concrete patch in canal invert.

North Unit Canal - Test Section N-6
3-inch shotcrete reinforced with Novocon steel fibers

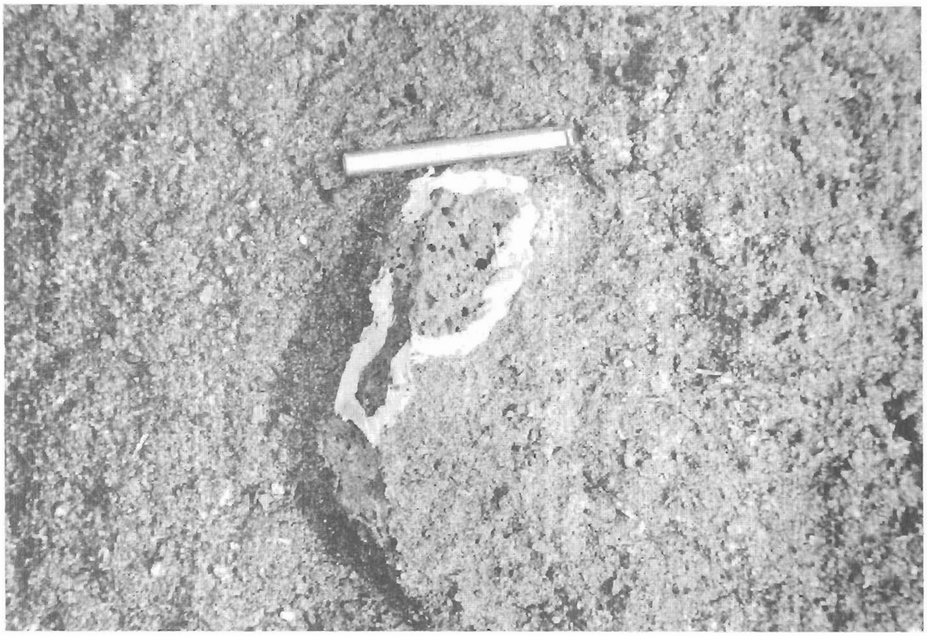


Photograph 118.—Contraction cracks were sealed with elastomeric sealant prior to the 1994 ponding test. Sealant is still flexible and appears well bonded.



Photograph 119.—Some cracks have grown significantly in the 2 years since application of the sealant.

North Unit Canal - Test Section N-6
3-inch shotcrete reinforced with Novocon steel fibers



Photograph 120.—Sealant used to seal around exposed subgrade rock where shotcrete was less than 1-inch thick.

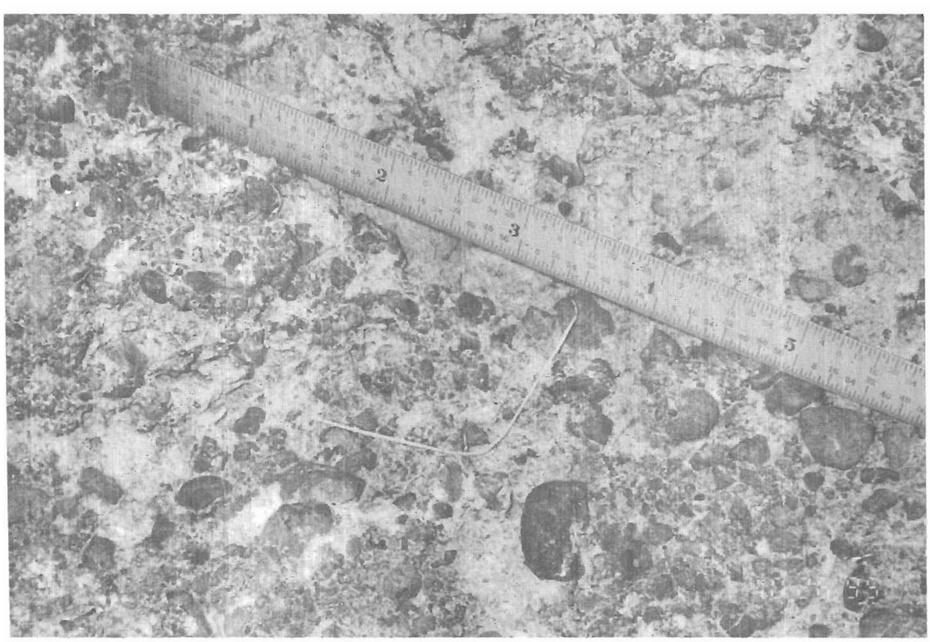
Photograph 121.—Possible animal burrow behind shotcrete at top of side slope.

Test Section N-7.—

Material:	3-inch shotcrete reinforced with Phillips polyfibers
Description:	Polyfibers are ¾-inch Phillips Fi-con polypropylene fibers
Construction Cost:	\$1.39 per square foot at fiber dosage of 1½ lb/yd^3 \$1.47 per square foot at fiber dosage of 3 lb/yd^3
Date Installed:	February 1992 (56 months old)
Location:	Station 25+00 to 30+00 (500 linear feet; 30,000 square feet)
Condition:	Excellent - Shotcrete performing well after 4½ years of service. This test section has some cracking, voids, exposed subgrade rocks, and vegetation typical of all the shotcrete test sections. Polyfibers are visible on the shotcrete surface. No 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 with 1.5 pound per cubic yard.
Maintenance:	Minimal maintenance required to date Performed: District patched a few small holes in shotcrete. Holes were typically 6-inch diameter or less (cost = \$100). Needed: None
Photographs:	122 through 127

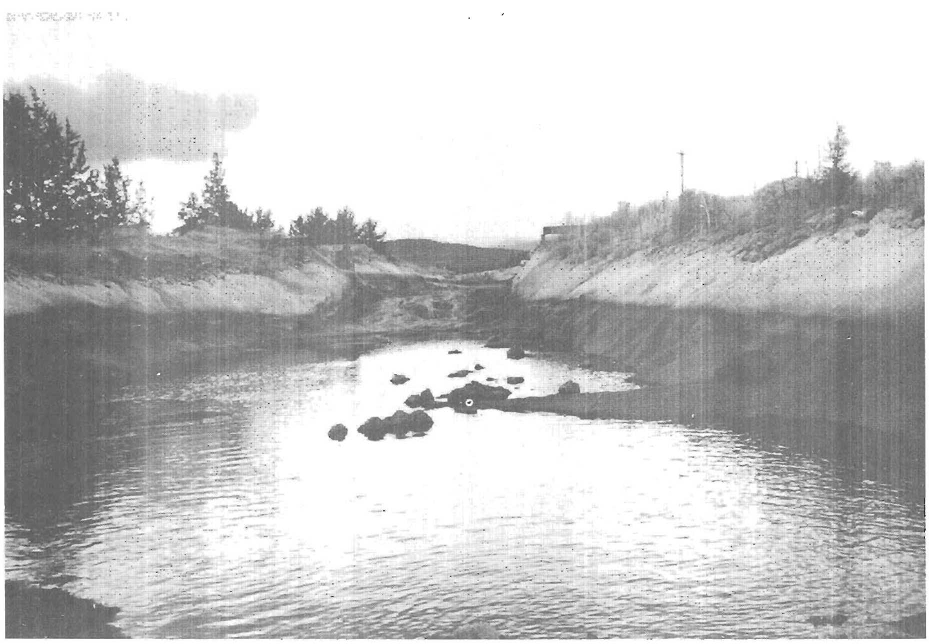
North Unit Canal - Test Section N-7
3-inch shotcrete reinforced with Phillips polyfibers

Photograph 122.—Canal overview - Excellent condition after 4½ years of service.

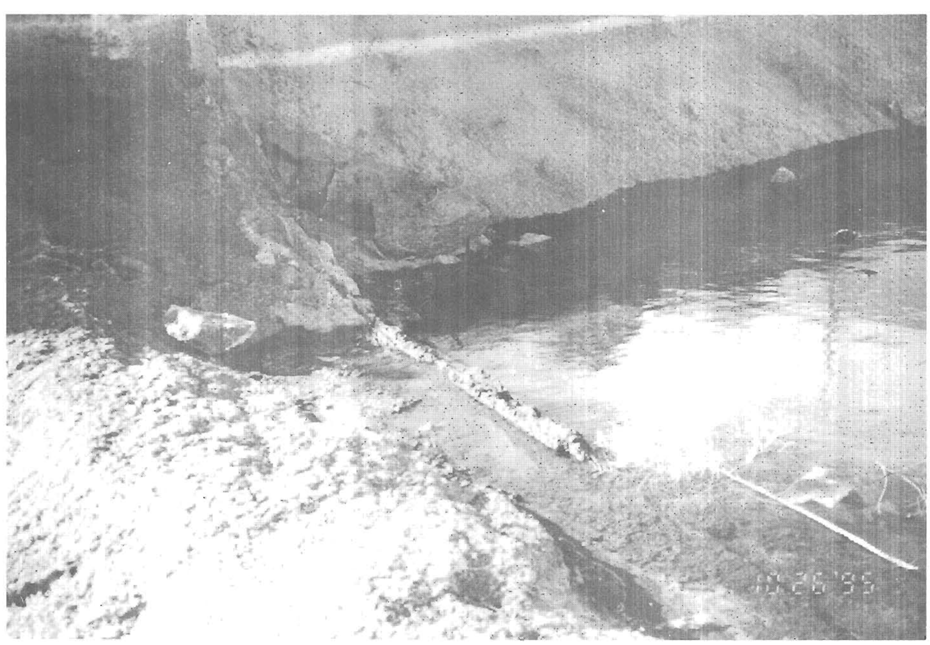


Photograph 123.—Higher velocities at drop structure have eroded surface cement, exposing aggregate, but shotcrete is holding up well.

North Unit Canal - Test Section N-7
3-inch shotcrete reinforced with Phillips polyfibers

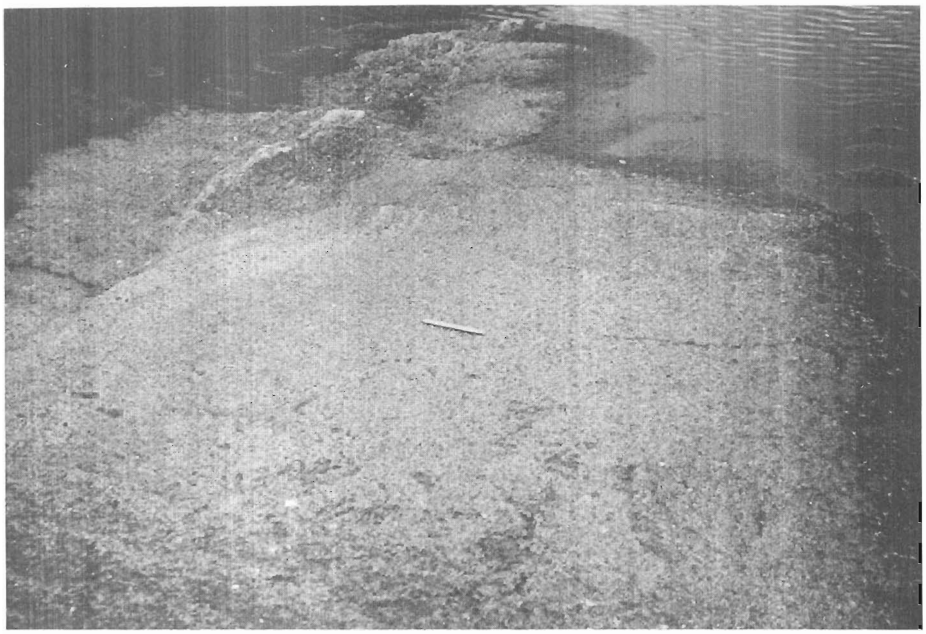


Photograph 124.—Drop structure at station 28+00.



Photograph 125.—Remains of dike at drop structure from the 1994 ponding test.

North Unit Canal - Test Section N-7
3-inch shotcrete reinforced with Phillips polyfibers



Photograph 126.—Transverse crack in canal invert measures about 10-feet long.

Photograph 127.—Close-up of invert crack.

Test Section N-8.—

Material: 3-inch shotcrete reinforced with Fibermesh polyfibers

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

Construction Cost: \$1.39 per square foot at a fiber dosage of 1½ lb/yd^3
\$1.47 per square foot at a fiber dosage of 3 lb/yd^3

Date Installed: February 1992 (56 months old)

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

Condition: Excellent - The shotcrete is performing well after 4½ years of service. This test section has some cracking, voids, exposed subgrade rocks, and vegetation typical of all the shotcrete test sections. Cracking appears to be slightly more prevalent than in Test Sections N-6 and N-7.

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

Maintenance: Minimal maintenance required to date

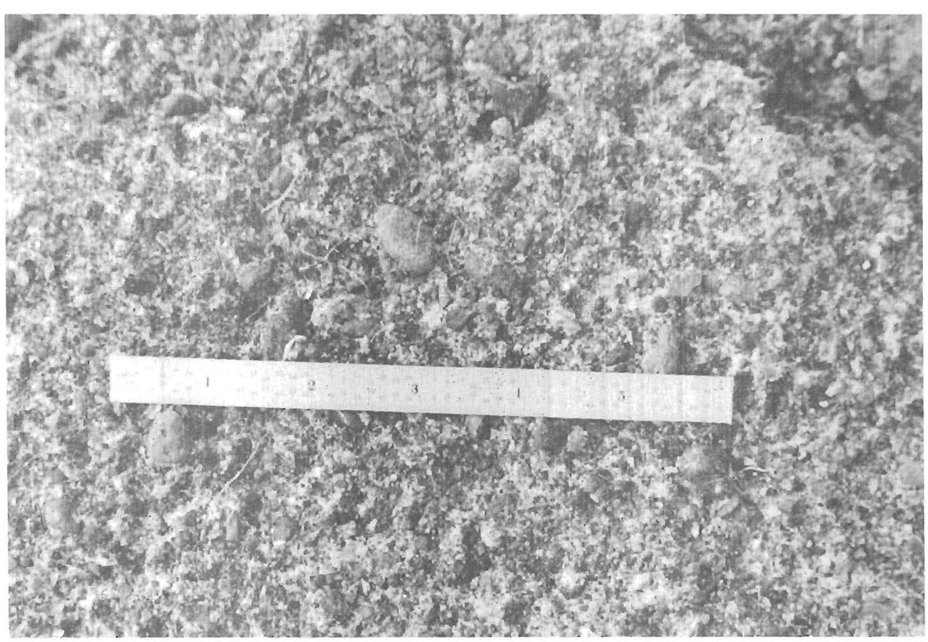
Performed: District patched a few small holes in shotcrete. Holes were typically 6-inch diameter or less (cost = \$100).

Needed: None

Photographs: 128 through 133

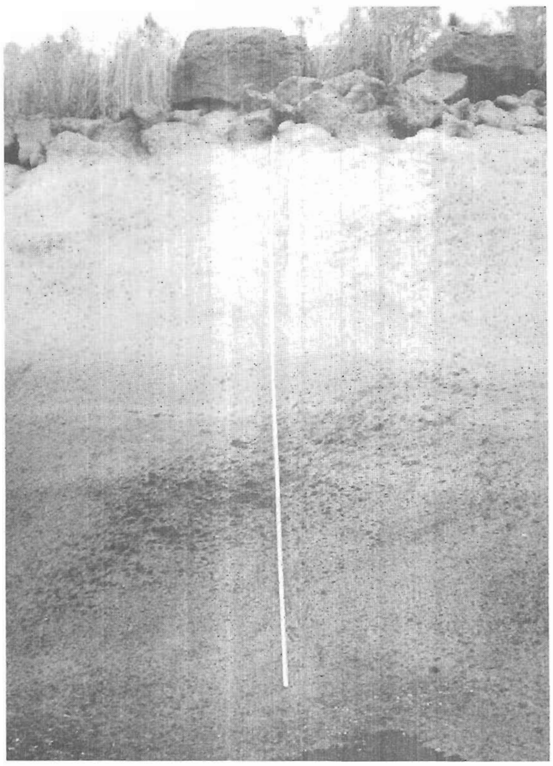
North Unit Canal - Test Section N-8
3-inch shotcrete reinforced with Fibermesh polyfibers

Photograph 128.—Canal overview - excellent condition after 4½ years of service.

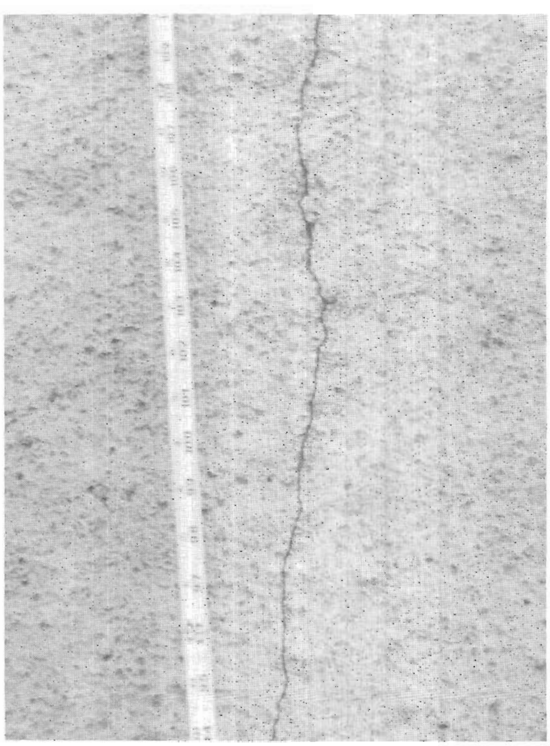


Photograph 129.—Polyfibers are visible on the surface of the shotcrete.

North Unit Canal - Test Section N-8
3-inch shotcrete reinforced with Fibermesh polyfibers

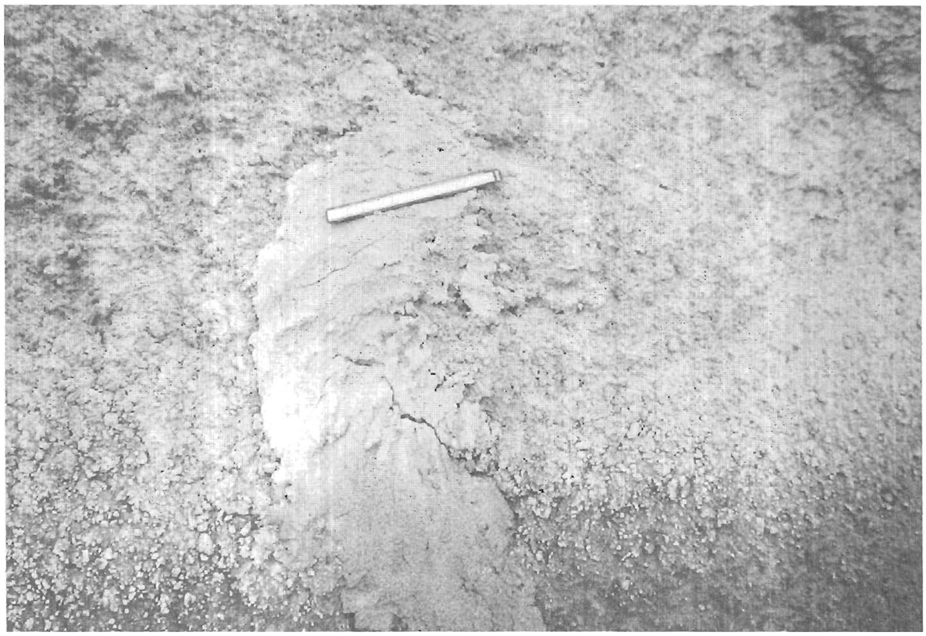


Photograph 130.—Transverse crack in sidewall is about 10-feet long.

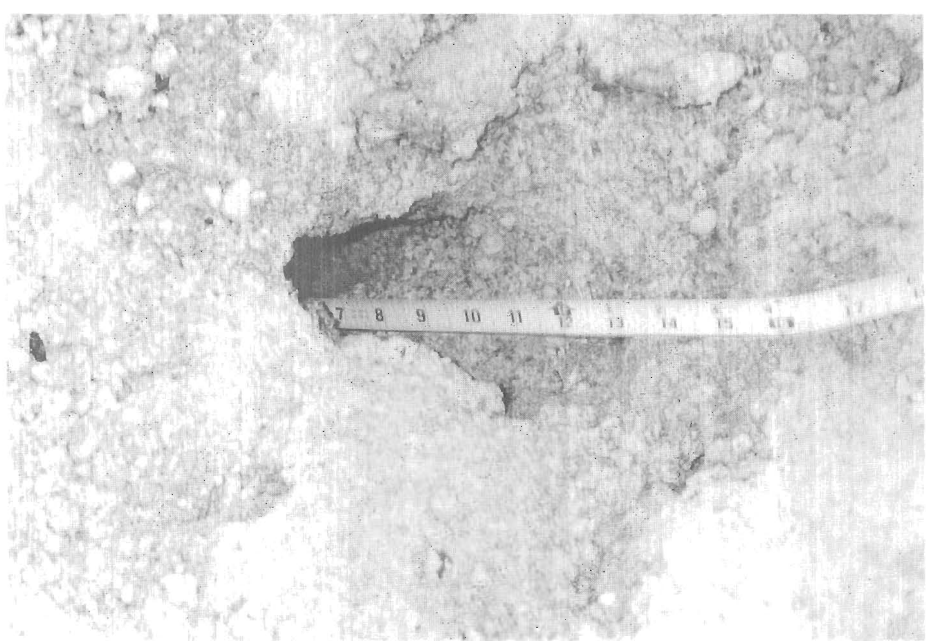


Photograph 131.—Close-up of transverse crack.

North Unit Canal - Test Section N-8
3-inch shotcrete reinforced with Fibermesh polyfibers



Photograph 132.—Irrigation district has patched several small holes where shotcrete was very thin because of protruding subgrade rock.



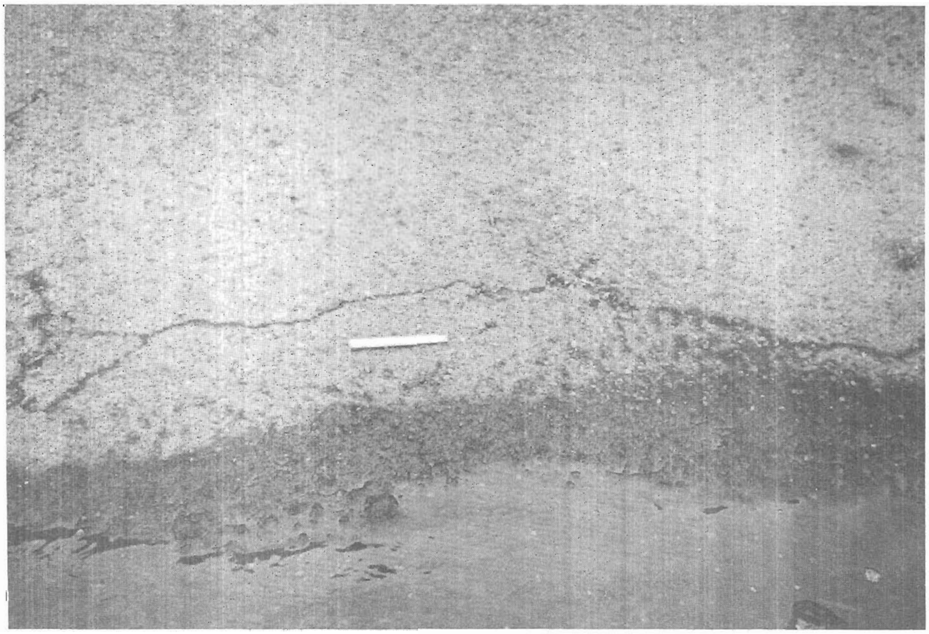
Photograph 133.—Hole in shotcrete is about 8-inches deep and above waterline. Since shotcrete is typically only 3-inches thick, this might be an animal burrow.

Test Section N-9.—

Material:	3-inch unreinforced shotcrete
Construction Cost:	$1.33 per square foot
Date Installed:	February 1992 (56 months old)
Location:	Station 35+00 to 40+00 (500 linear feet; 30,000 square feet)
Condition:	Excellent - Shotcrete performing well after 4½ years of service This test section has some cracking, voids, exposed subgrade rocks, and vegetation typical of all the shotcrete test sections. Cracking appears to be slightly more prevalent than in Test Sections N-6 and N-7.
Maintenance:	Minimal maintenance required to date Performed: District patched a few small holes in shotcrete. Holes were typically 6-inch diameter or less (cost = $100). Needed: None
Photographs:	134 through 139

North Unit Canal - Test Section N-9
3-inch unreinforced shotcrete

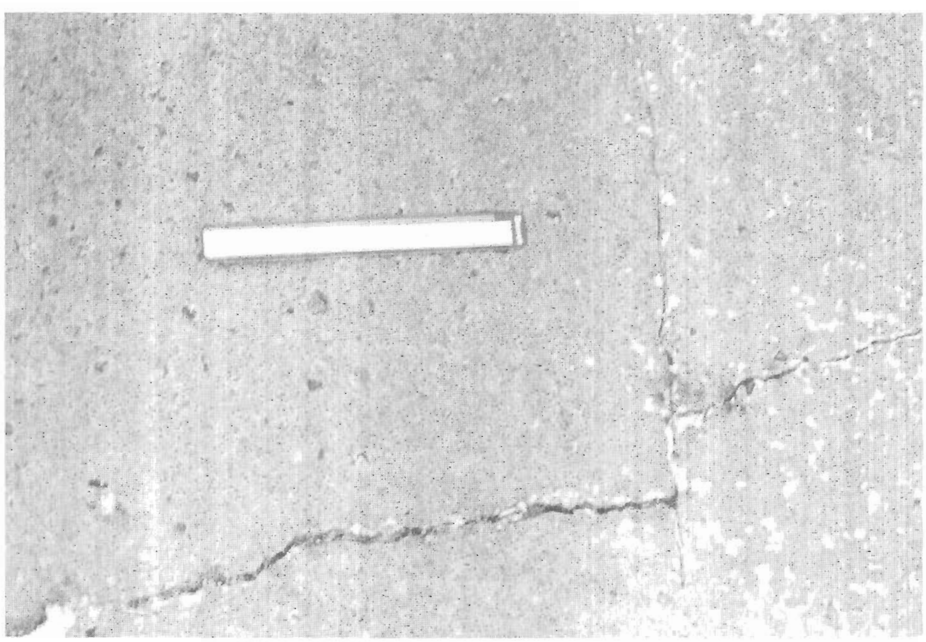
Photograph 134.—Canal overview - excellent condition after 4½ years of service.



Photograph 135.—This 5-foot-long crack is one of the few longitudinal cracks found in the shotcrete test sections.

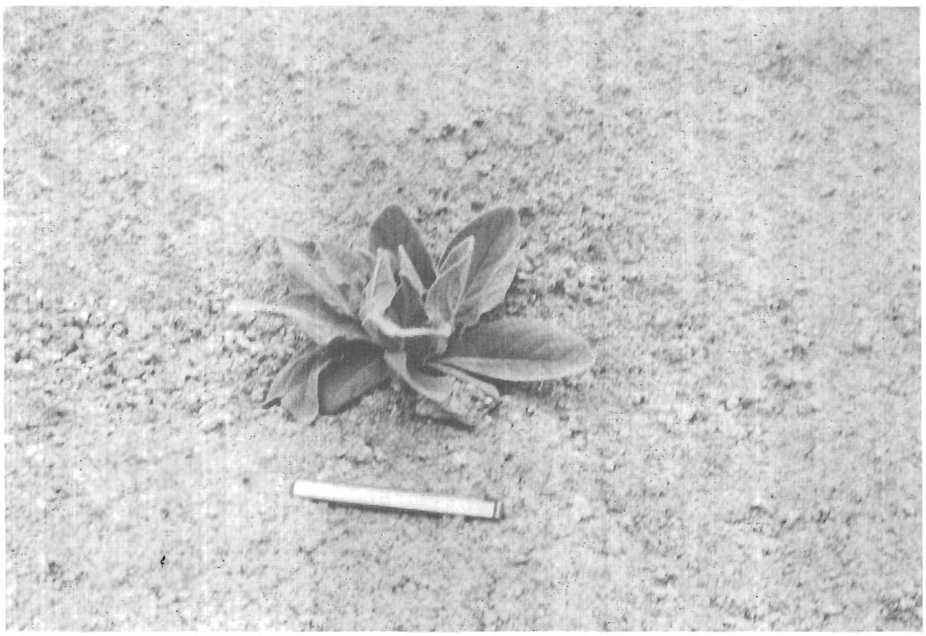
North Unit Canal - Test Section N-9
3-inch unreinforced shotcrete

Photograph 136.—The most severe cracking in any of the shotcrete test sections is shown in this photo at station 31+00.

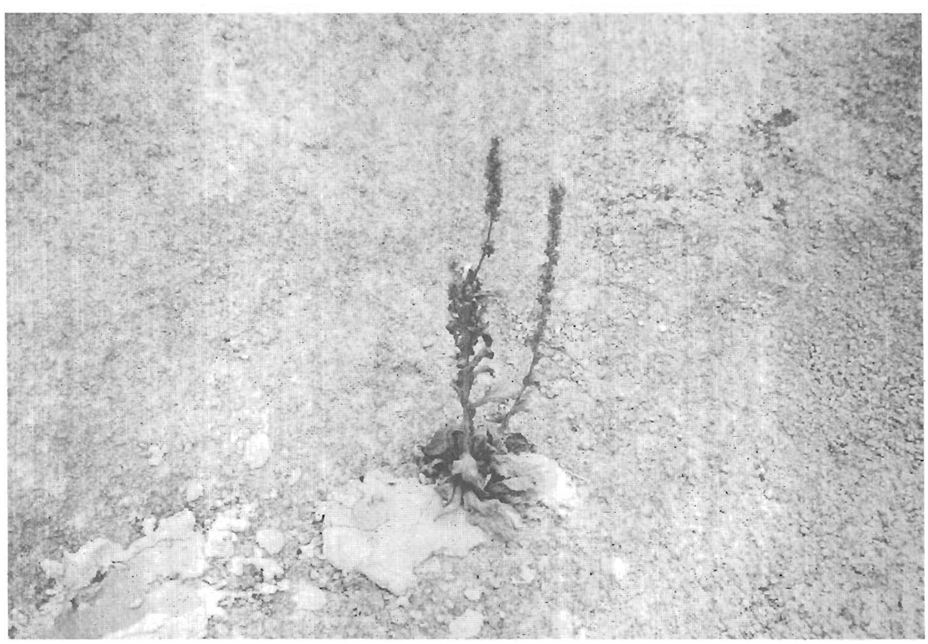


Photograph 137.—Close-up of cracks at station 31+00.

North Unit Canal - Test Section N-9
3-inch unreinforced shotcrete



Photograph 138.—Typical vegetation growing out of shotcrete side walls



Photograph 139.—The district patched a couple of small holes at this location, but vegetation still finds a toe hold.

Tumalo - Bend Feed Canal

Test Section T-1.—

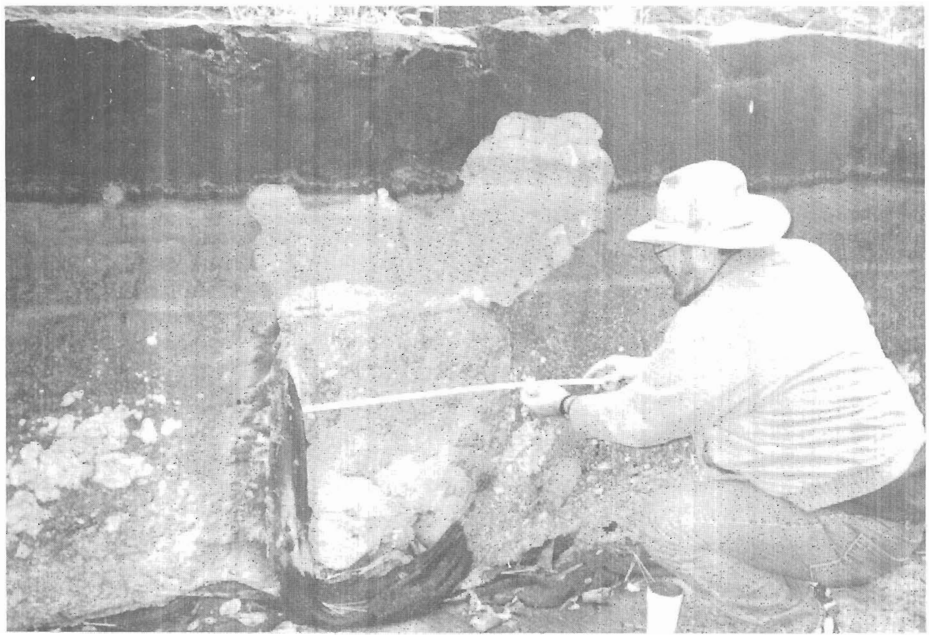
Material:	Liquid Boot over an existing concrete flume
Description:	Liquid Boot is a spray-applied neoprene-polymer-modified asphalt emulsion.
Construction Cost:	$1.45 per square foot
Date installed:	April 1994 (30 months old)
Location:	Bend Feed Canal Headworks (75 linear feet; 1,575 square feet)
Condition:	Poor - The Liquid Boot is completely disbonded from the 11-foot invert and has mostly washed away. Any Liquid Boot remaining in the invert has rolled up into the corners against the side walls. Liquid Boot on the 5-foot vertical side walls has lots of small tears and pinholes, but is still mostly intact and well bonded. Disbonded Liquid Boot seems brittle in the cold morning air (around freezing). Based on the knowledge gained from the construction of this test section, Liquid Boot has adopted several changes in the construction process that would 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 side walls one day and the invert the next would have minimized the amount of water released 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 is required; however, no maintenance is planned for this test section, as the repairs will probably also fail. This section will continue to be monitored to evaluate the long-term performance of the Liquid Boot that is still bonded to the stone and cement side walls.
Photographs:	140 through 143

Tumalo Irrigation District - Test Section T-1
Liquid Boot over an existing concrete flume

Photograph 140.—Canal overview - poor condition after 2½ years of service.

Photograph 141.—Liquid Boot has completely disbonded from the concrete invert and rolled up into the corners against the side walls.

Tumalo Irrigation District - Test Section T-1
Liquid Boot over an existing concrete flume



Photograph 142.—Large disbonded area on the right side wall measures 2 feet by 3 feet.

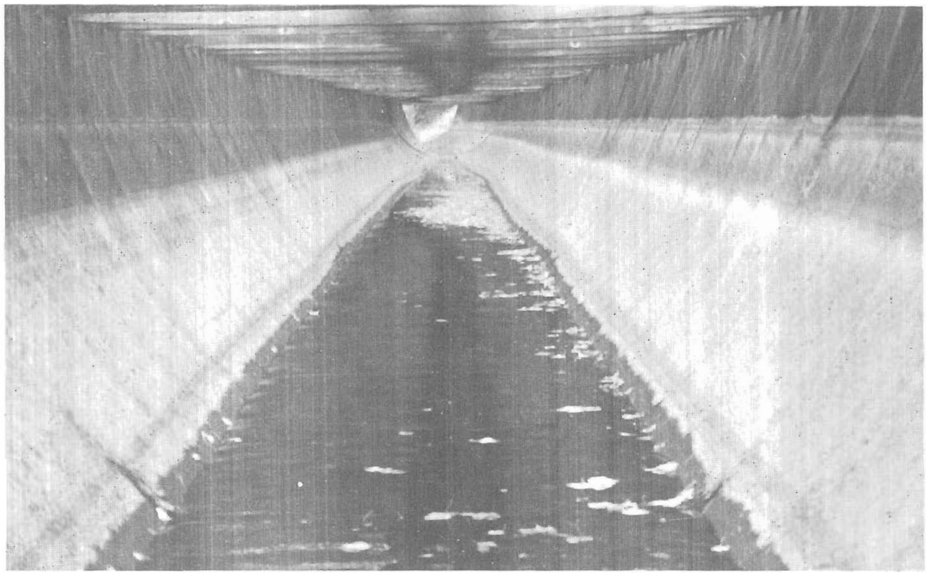
Photograph 143.—Small disbonded blister on left side wall measures about 12 inches in diameter.

Test Section T-2.—

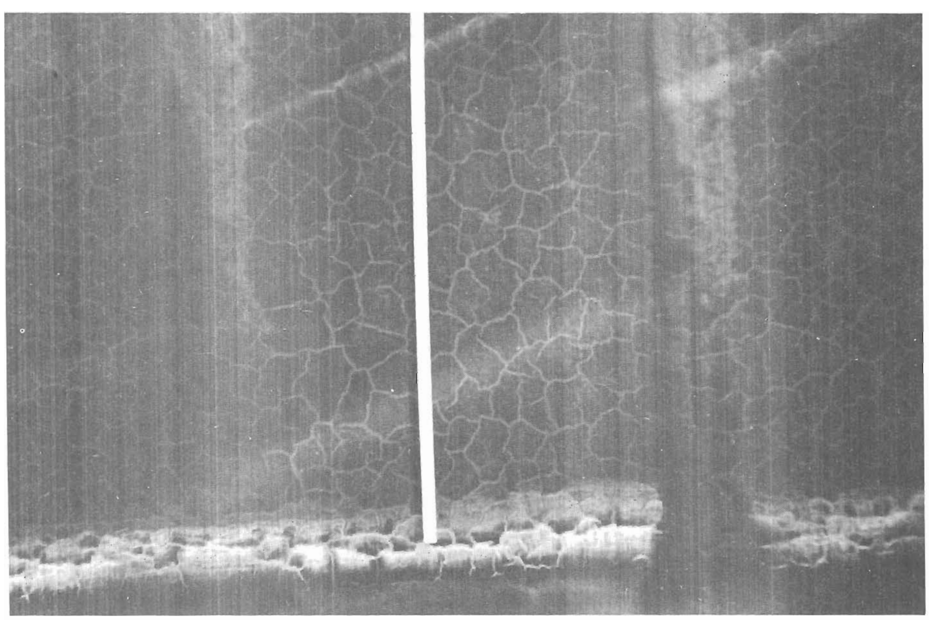
Material:	Liquid Boot over a sandblasted steel flume
Description:	Liquid Boot is a spray-applied neoprene-polymer-modified asphalt emulsion.
Construction Cost:	$1.84 per square foot
Date installed:	April 1994 (30 months old)
Location:	Flume #4 - Bend Feed Canal (463 linear feet; 7,871 square feet)
Condition:	Very Good - The Liquid Boot is well bonded to 99 percent of the steel flume. No leakage is evident. After being drained for 3 to 4 weeks, 6 to 12 inches of standing water is still in the flume, except at the clean-out drain which is dry (appears to be the high point). This standing water shows that the loss rate (seepage rate) is essentially zero. Several blisters (40 to 50) have developed in the Liquid Boot, directly over the old tar material in the seams between the flume's 3-foot-wide steel panels. All of the blisters are in the bottom of the invert, except for a couple, which are 1 to 2 feet up the side. The blisters typically measure 6 inches in diameter, with the largest measuring 6 inches across by 48 inches long. All of the blisters are full of sand and sediment. Apparently, the Liquid Boot is poorly bonded to the old tar material, and the Liquid Boot deforms and blisters under the force of the flowing water. Once a small hole develops in the blister, the flowing water deposits sand and debris, causing the blister to grow in size. The water released from the Liquid Boot emulsion during construction probably contributed to the poor bond in the invert. Finally, the blisters are more prevalent in the downstream shaded end of the flume. During construction, the cooler temperatures in the shaded areas might have retarded cure, and weakened the bond. The geotextile embedded in the Liquid Boot at the clean-out drain is partially disbonded but in fair condition. The Liquid Boot has disbonded from the concrete at the upstream and downstream transitions. Based on the experience gained from the construction of this test section, the Liquid Boot manufacturer (LBI) has 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 side walls first, then coating the invert after the water released from the Liquid Boot on the side walls has evaporated.

Maintenance:	Minor maintenance is required at this time.	
	Performed:	In 1995, the District attempted to repair the blisters but could not get the Liquid Boot Trowel Grade to bond to the existing Liquid Boot. The district then used a roofing tar to make the repairs (cost = $200).
	Needed:	The District still needs to repair the blisters as the roofing tar repairs were not successful. LBI has promised to provide on-site technical support and an improved repair procedure.
Photographs:	144 through 149	

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

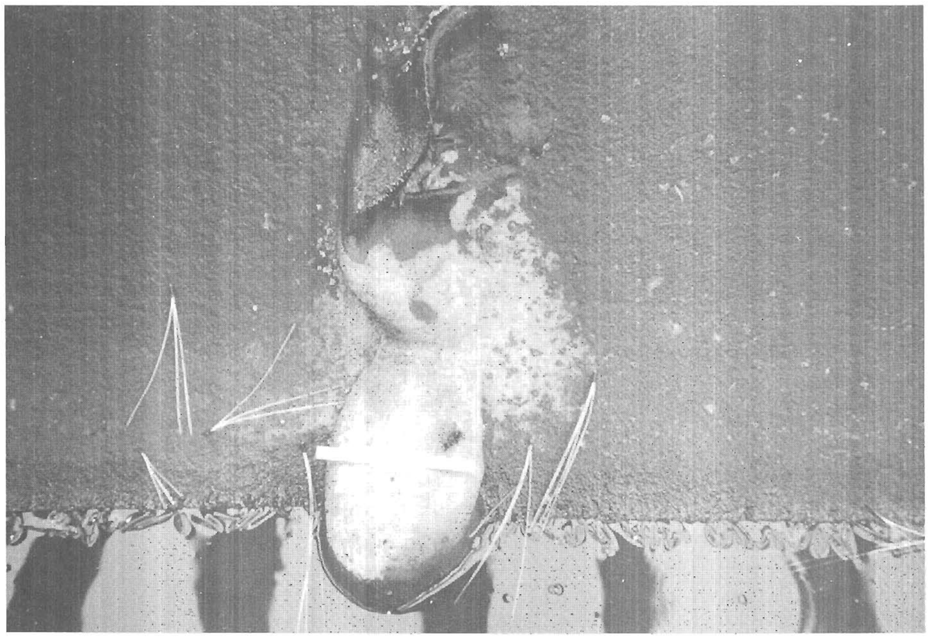


Photograph 144.—Flume overview - very good condition after 2½ years of service.

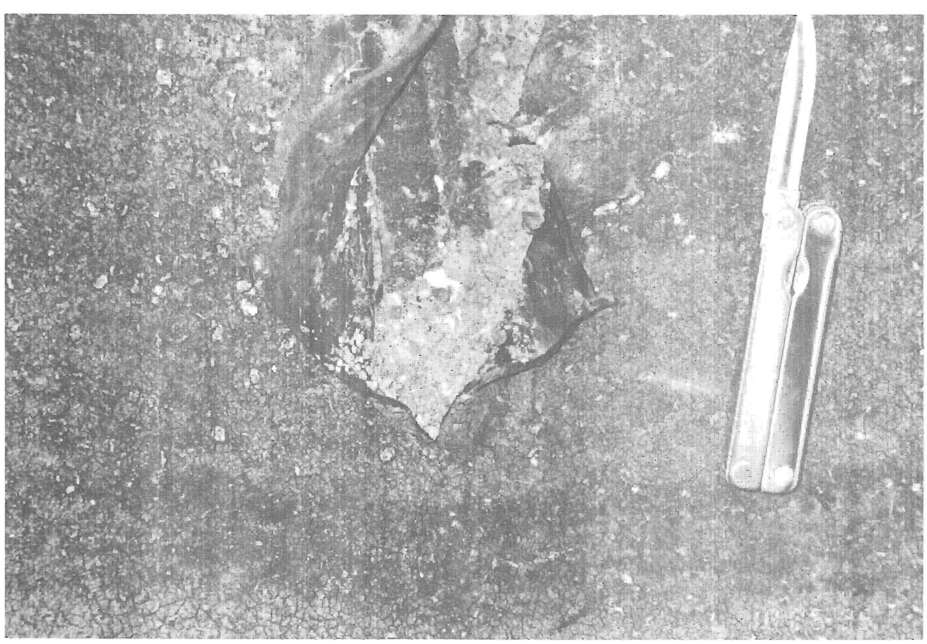


Photograph 145.—Liquid Boot on the sidewalls is alligator cracking where exposed to sunlight.

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

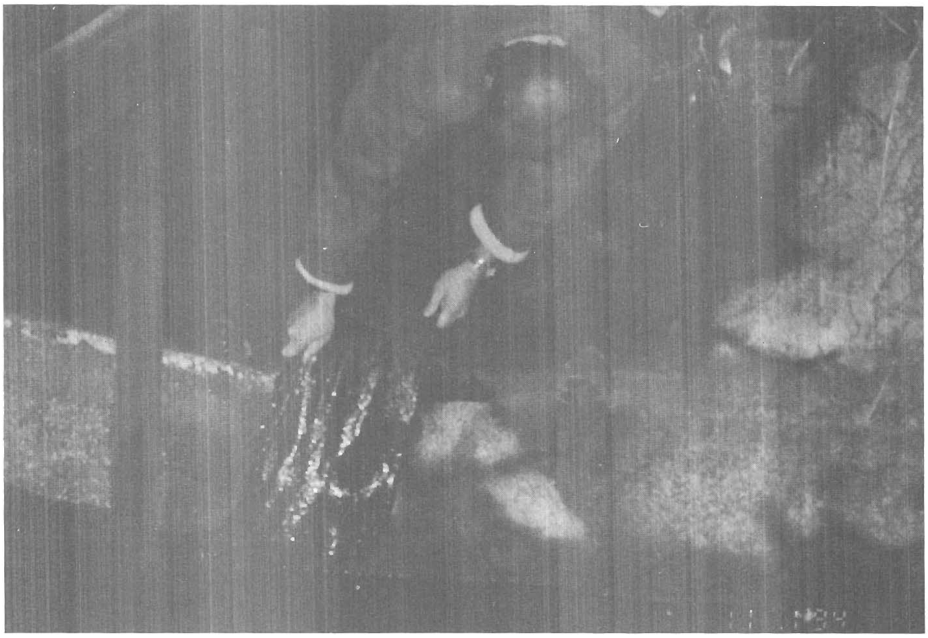


Photograph 146.—Typical blister found in the invert measures 6-inches across and 1- to 2-feet long.



Photograph 147.—When cut open, blisters are full of sediment.

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



Photograph 148.—Liquid Boot is poorly bonded at the upstream transition.

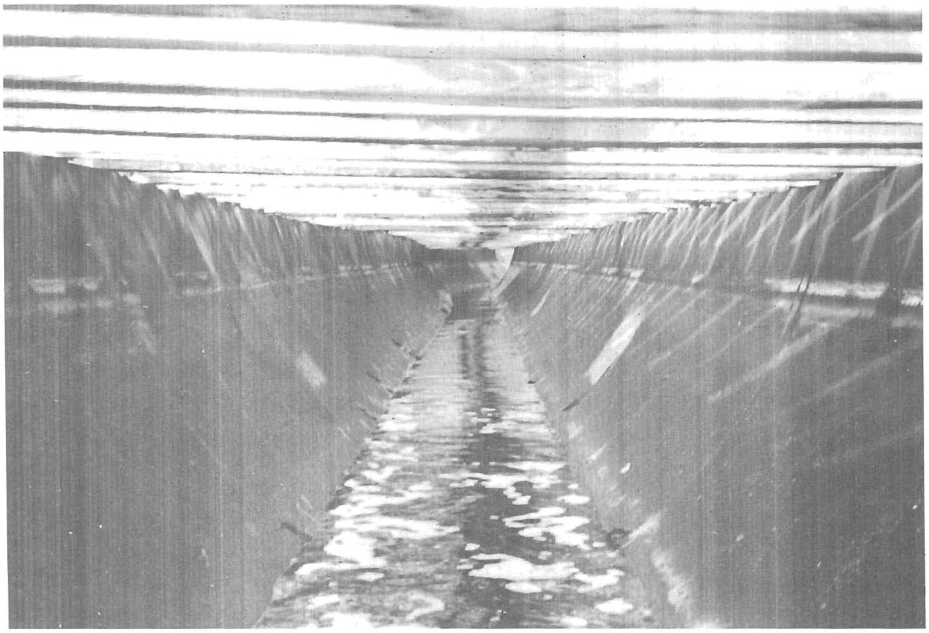
Photograph 149.—Liquid Boot has completely washed away from the upstream and downstream transitions

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:	$1.20 per square foot
Date installed:	April 1995 (18 months old)
Location:	Klippel Flume - Bend & Tumalo Feed Canals (267 linear feet; 4,539 square feet)
Condition:	Very Good - The Liquid Boot is well bonded to 99 percent of the steel flume. No leakage is evident. After being drained for 3 to 4 weeks, 3 inches of standing water is still in much of the flume. Several blisters (about 40) have developed in the Liquid Boot, directly over the old tar material in the seams between the flume's 3-foot-wide steel panels. All of the blisters are in the bottom of the invert, except for a couple, which are 1 to 2 feet up the side. The blisters typically measure 4 inches across, with the largest measuring 6 inches across by 24 inches long. All of the blisters are full of sand and sediment. Apparently the Liquid Boot is poorly bonded to the old tar material, and the Liquid Boot deforms and blisters under the force of the flowing water. Once a small hole develops in the blister, the flowing water deposits sand and debris, causing the blister to grow in size. The water released from the Liquid Boot emulsion during construction probably contributed to the poor bond in the invert. Also, the blisters are more prevalent in the upstream, shaded end of the flume. During construction, the cooler temperatures in the shaded areas might have retarded cure, and weakened the bond. No cut off trench or geotextile was used on this test section. Based on the experience gained from the construction of 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 side walls first, then coating the invert after the water released from the Liquid Boot on the side walls has evaporated.
Maintenance:	Minor maintenance is required at this time. The District needs to cut open the blisters, trim away any unbonded material, then patch with Liquid Boot Trowel Grade.
Photographs:	150 through 153

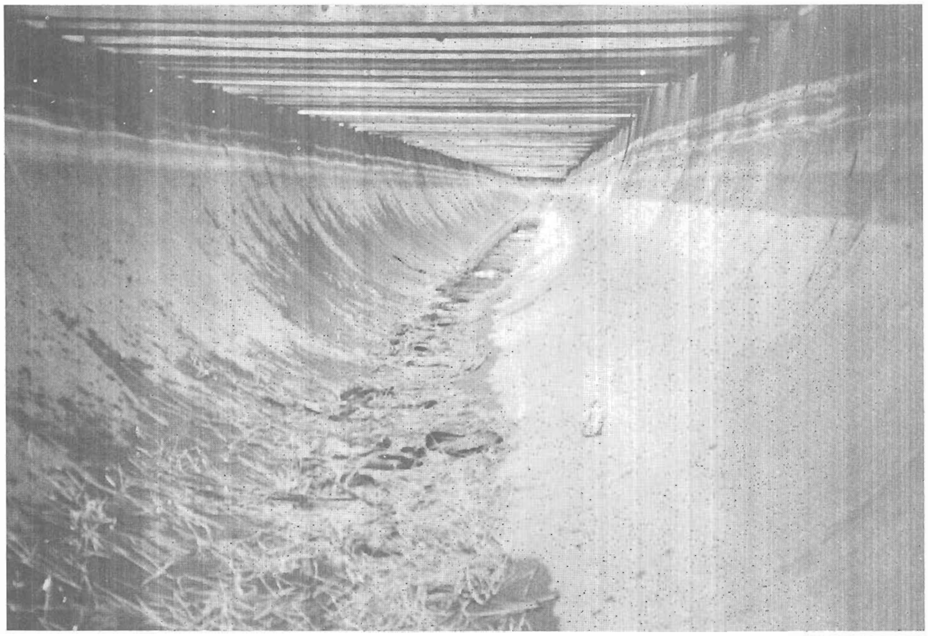
Tumalo Irrigation District - Test Section T-3
Liquid Boot over a broomed steel flume

Photograph 150.—Flume overview - very good condition after 1½ years of service.

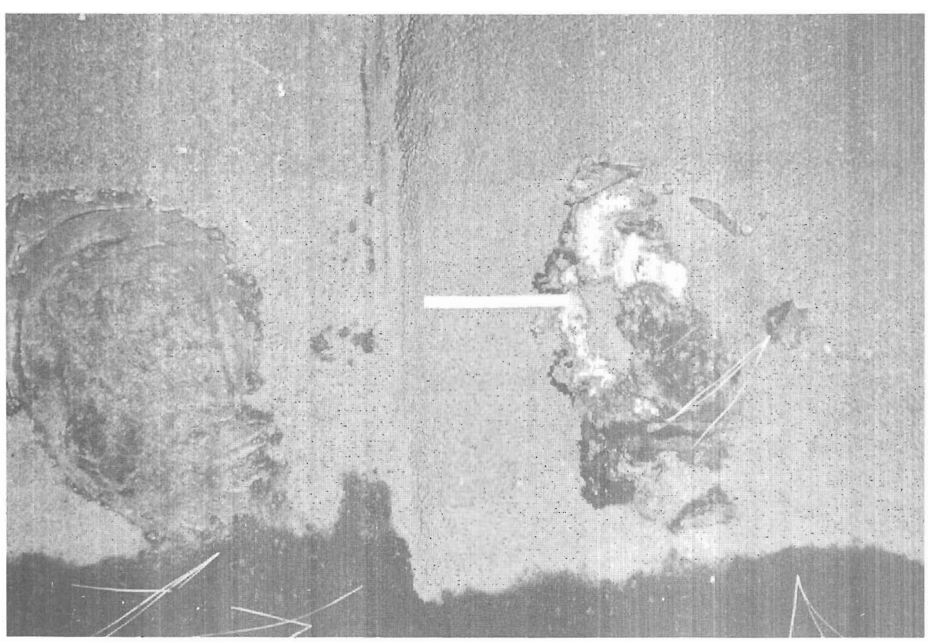


Photograph 151.—Flume interior - very good condition after 1½ years of service.

Tumalo Irrigation District - Test Section T-3
Liquid Boot over a broomed steel flume



Photograph 152.—Most of the blisters are in the upstream shaded end of the flume.



Photograph 153.—Patch on left was made with the Liquid Boot trowel-grade. Blister on right in need of repair.

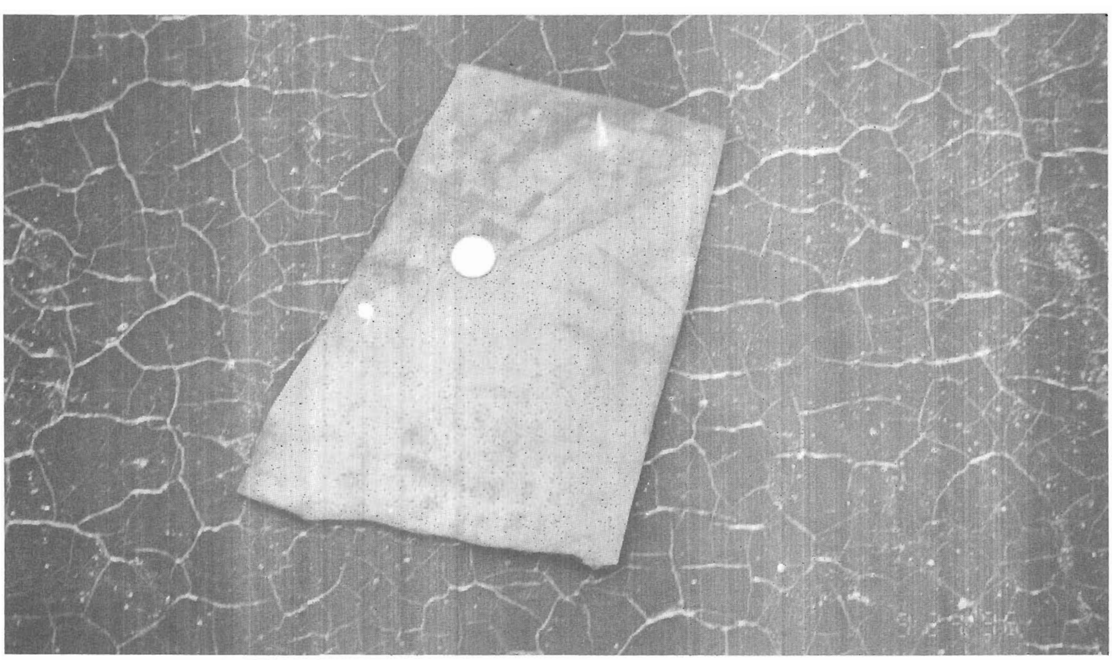
Lugert-Altus Irrigation District

Test Section L-1.—

Material:	Teranap exposed geomembrane
Description:	Teranap is an elastomeric bitumen geomembrane, combining Styrene-Butadiene-Styrene (SBS) polymer and asphalt with a polyester reinforcement. Teranap is available in two thicknesses: 120-mil Teranap 331 and 160-mil Teranap 431.
Construction Cost:	160-mil exposed Teranap = $1.39 per square foot 120-mil exposed Teranap = $1.22 per square foot
Date Installed	May 1994 (29 months old)
Location:	West Canal - Lugert-Altus Irrigation District (2400 linear feet; 70,000 square feet)
Condition:	Very Good - After 2½ years of service (3 irrigation seasons), the Teranap is in very good condition. The Teranap shows some surface alligator cracking, but is still quite flexible. The seams are well bonded, and small areas of standing water indicate that the seepage rate is essentially zero (less than 0.1 feet/day). Little to no sediment has collected in this reach of canal. In September 1996, a large storm deposited about 4½ inches of rain in 1 hour. Surface runoff from the area north and west of the test section flows into a small drainage ditch that crosses the canal 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 stakes (rebar) driven through the liner, and repaired the tears with a propane torch and additional Teranap where needed. The district plans to raise the berm to prevent future washouts, and is cleaning and enlarging the drainage ditch to increase capacity.
Maintenance:	The irrigation district repaired the Teranap after the washout. (cost = $3,000?).
Photographs:	154 through 165

Lugert-Altus Irrigation District - Test Section L-1
Exposed Teranap

Photograph 154.—Canal overview - very good condition after 2½ years of service.



Photograph 155.—An unaged piece of Teranap is placed on the aged Teranap for comparison. The aged Teranap shows surface cracking (alligator cracking) which is normal for this product.

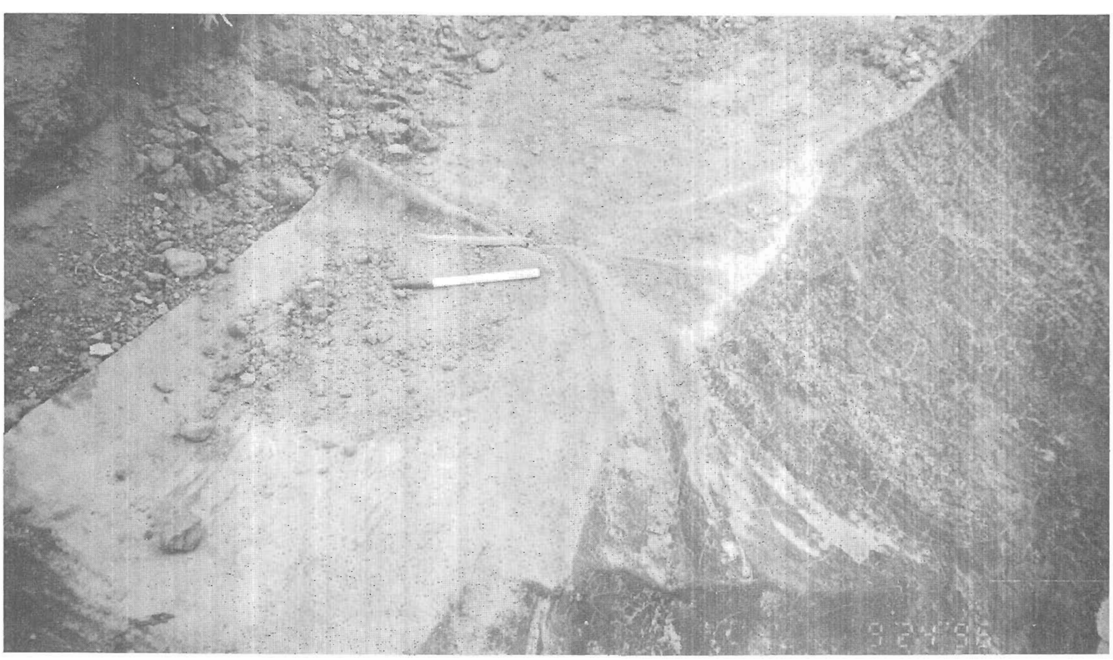
Lugert-Altus Irrigation District - Test Section L-1
Exposed Teranap

Photograph 156.—On the upstream end of the canal, about 300 linear feet of Teranap washed-out on the west bank.

Photograph 157.—Wash-out extends around the first bend.

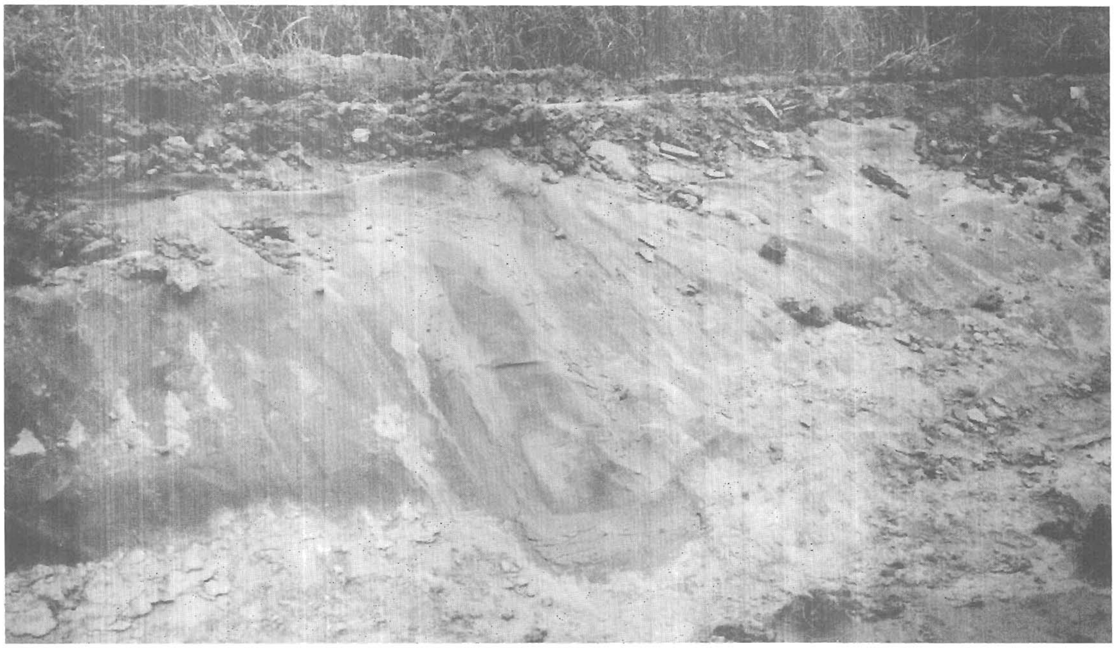
Lugert-Altus Irrigation District - Test Section L-1
Exposed Teranap

Photograph 158.—Irrigation district personnel reshaped the subgrade and pulled the Teranap back into position.

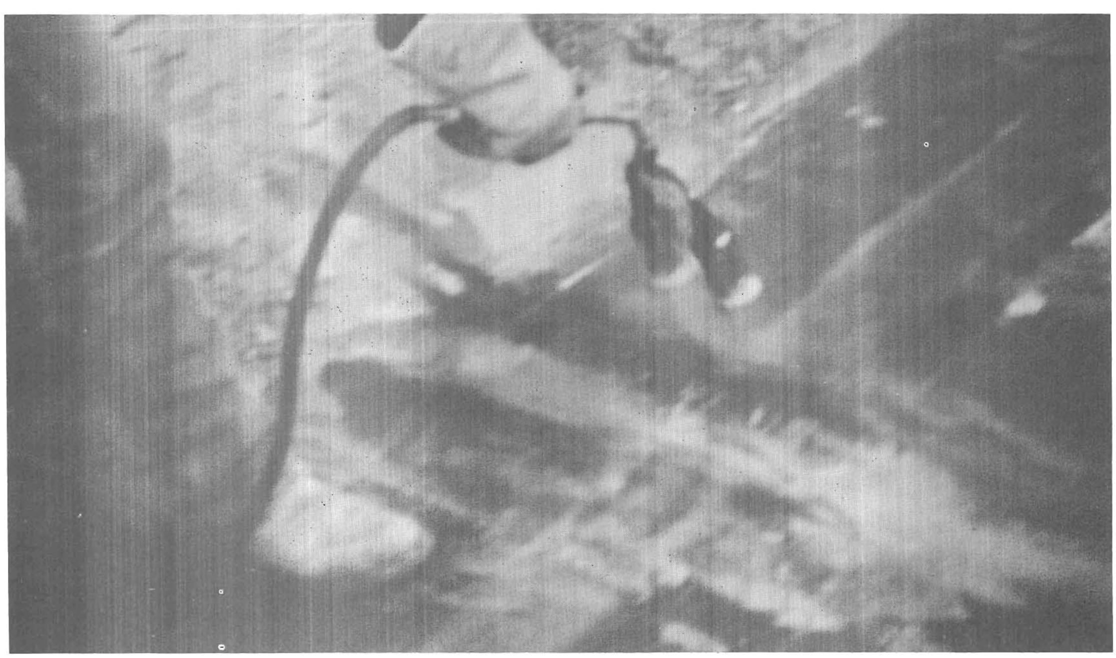


Photograph 159.—The Teranap was resecured into the 1-foot anchor berm with rebar driven through the Teranap.

Lugert-Altus Irrigation District - Test Section L-1
Exposed Teranap

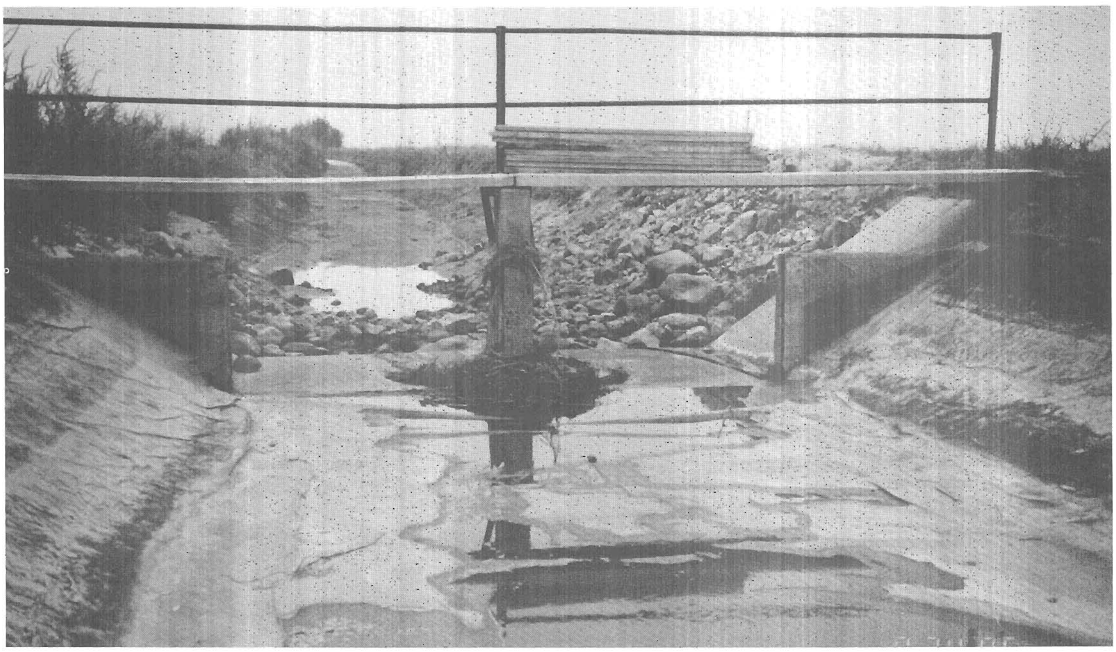


Photograph 160.—Tears in the Teranap were repaired with a patch of new Teranap.



Photograph 161.—District personnel applied the Teranap patches with a propane torch.

Lugert-Altus Irrigation District - Test Section L-1
Exposed Teranap



Photograph 162.—Teranap at the downstream check structure
is in very good condition, needing only minor repairs.

Photograph 163.—Teranap at this outlet structure needs minor repair

Lugert-Altus Irrigation District - Test Section L-1
Exposed Teranap

Photograph 164.—These rebar stakes show that the subgrade has subsided 1 to 2 inches at this location.

Photograph 165.—District is cleaning out and increasing capacity of drainage channel that crossed canal at upstream siphon.

CHAPTER IV
SEEPAGE ANALYSIS

North Unit Post-Construction Ponding Test

In November 1994, a post-construction ponding test was performed on the North Unit Main Canal to determine the seepage rate through the new shotcrete test sections. A pre-construction ponding test was conducted in 1991 between station -2+05 and station 12+22 (1,400 linear feet). The pre-construction test indicated an average seepage rate of 4.20 ft/day (ft^3/ft^2-day).

For the post-construction ponding test, the North Unit Irrigation District performed some minor repairs to return the ponded section to its "new" condition. These repairs consisted primarily of caulking about 60 linear feet of cracks in the shotcrete. The district then constructed a 4-inch thick concrete dike between two old flume piers at canal station 28+00, backing-up water to station 19+60 (840 linear feet). The concrete dike held water to a depth of approximately 5 feet, and no leakage was evident through the concrete wall. The upstream end of the pond (station 19+60) was at a natural drop in the canal and therefore no upstream dike construction was needed. The staff gage for monitoring water depth was located on the upstream side of the concrete wall. The staff gage was set with the 0.00 mark at the canal invert, and therefore, the readings indicate water depth at the downstream end of the ponding test section. Staff gage readings during the ponding test were collected by the irrigation district personnel. All the water loss in the test section was attributed to seepage through the shotcrete lining. The lining test section was a combination of approximately 500 linear feet of steel reinforced shotcrete and approximately 300 linear feet of polyfiber reinforced shotcrete. Ponding test data were collected over a 48-hour period, and the results are shown in table 10. These data are plotted in figure 3, showing that the seepage rate decreases with time as the ground beneath the canal becomes saturated.

Table 10.—North Unit Main Canal - Post-Construction Ponding Test
November 1994

Staff Gage (ft)	Wetted Area (ft^2)	Pond Volume (ft^3)	Average Wetted Area (ft^2)	Change in Volume (ft^3)	Time Interval (hours)	Seepage Rate (ft^3/ft^2-day)
5.08	52,044	180,874				
			51,878	- 5,016	3	0.580
4.98	51,712	175,858				
			51,579	- 3,980	4	0.617
4.90	51,447	171,878				
			50,874	-16,749	17	0.465
4.56	50,301	155,129				
			50,182	- 3,409	3	0.408
4.49	50,064	151,720				
			49,997	- 1,930	4	0.309
4.45	49,930	149,790				
			49,458	-12,968	17	0.370
4.18	48,987	136,821				

The time-weighted average seepage rate for this ponding test is 0.44 ft/day. Other researchers list seepage rates of 0.31 ft/day for cement grout[3] and 0.33 ft/day for a concrete lining.[4] Due to the irregular subgrade of the North Unit Canal, and the subsequent difficulty in obtaining a uniform thickness of shotcrete, the loss rate of 0.44 ft/day is considered to be a realistic value.

The reduction in seepage rates from 4.20 ft/day to 0.44 ft/day is quite significant (one order of magnitude). Future test sections could realize additional water savings by incorporating a geomembrane beneath the shotcrete lining. This modification could reduce the seepage rate to the about 0.07 ft/day, which is Reclamation's anticipated seepage rate for a well-constructed concrete lining with good joint sealant.

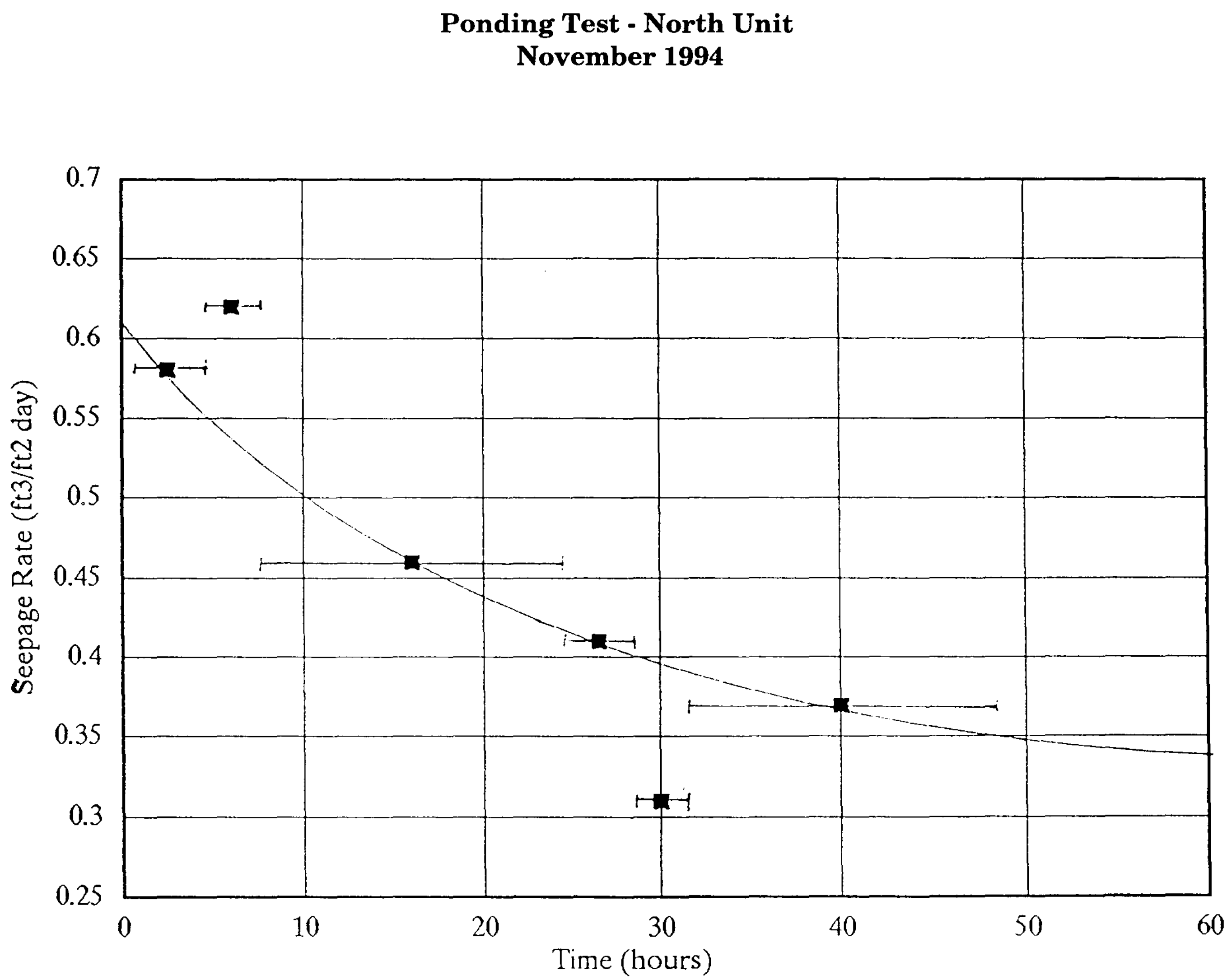


Figure 3.—Post-construction seepage data for shotcrete on North Unit Canal.

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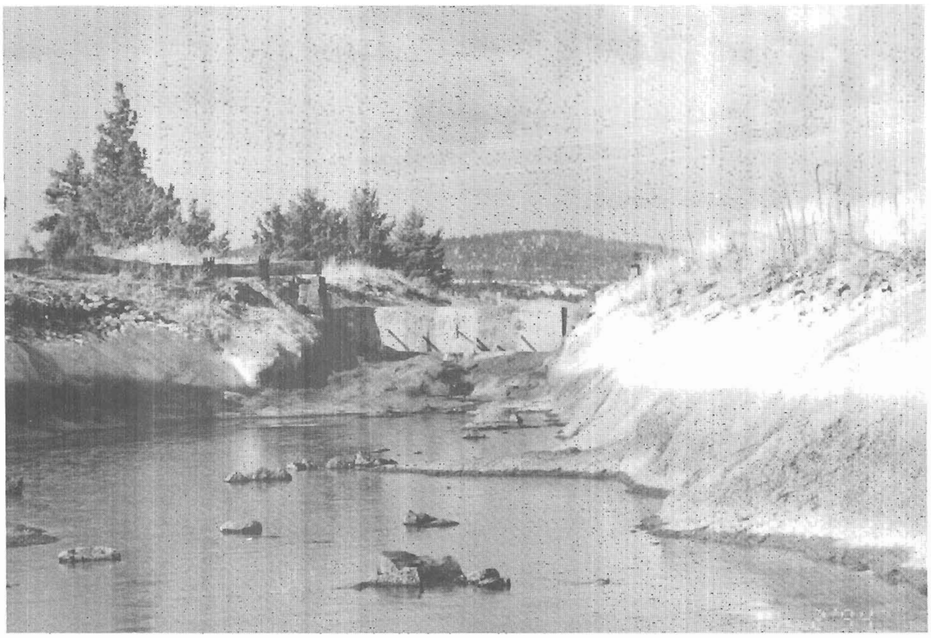
[3] A.P. Davis and H.M. Wilson, *Irrigation Engineering* (1919)

[4] *Reclamation Hydraulic Design Data* (1948)

Ponding Test - North Unit Main Canal shotcrete test sections



Photograph 166.—Dike for ponding test at station 28+00.

Photograph 167.—Concrete dike is 4 inches thick.

Ponding Test - North Unit Main Canal shotcrete test sections

Photograph 168.—Ponded water behind dike.

Photograph 169.—Staff gage for ponding measurements.

Arnold Irrigation District—Seepage Analysis

Arnold Irrigation District Test Sections A-7 and A-8 are identical except that Test Section A-7 has a 40-mil PVC geomembrane underliner beneath the 3-inch grout-filled mattress, while Test Section A-8 has only the 3-inch grout-filled mattress without any geomembrane underliner. This side-by-side installation allows a direct comparison of the performance of 3 inches of concrete with and without a geomembrane underliner.

The irrigation district has noticed that when the water is turned off in the fall, Test Section A-7 holds standing water all through the winter, while Test Section A-8 holds standing water for only about 2 weeks. This evidence is only qualitative, but demonstrates the lower seepage rate that one would expect with the geomembrane underliner. Side-by-side ponding is planned for 1998.

Tumalo Irrigation District—Seepage Rates

Test Section T-1—Test Section T-1 is a concrete flume immediately downstream from the diversion dam on the Deschutes River. Before lining with Liquid Boot, this flume leaked significantly through the deteriorated concrete side walls. Water leaking from the flume returned to the nearby Deschutes River, and therefore was not a major concern. Pre-construction seepage was estimated by the District at about 5 cfs (about 2,000 gpm), which is equivalent to about 300 ft^3/ft^2-day (based on a length of 75 feet, and a wetted perimeter of 19 feet). The post-construction seepage rate is estimated at about 0.5 cfs (200 gpm) or about 30 ft^3/ft^2-day.

Test Section T-2—Flume #4 is a 463-feet-long elevated steel flume on the Bend Feed Canal. The flume is built on a wooden trestle that crosses a small stream and valley. Before lining with Liquid Boot, this flume leaked significantly at the seams between the 3-foot metal panels. Also, the metal itself was starting to corrode and had pinholes which were contributing to the seepage. The irrigation district routinely shoveled cinders into the flume to reduce the seepage. Water leaking from the flume would eventually end up in the small stream in the valley below. Pre-construction ponding tests were not performed; however, Tumalo Irrigation District personnel estimated the seepage at 5 cfs (2,000 gpm), which is equivalent to 85 ft/day (based on a length of 463 feet, and a wetted perimeter of 11 feet). The post-construction seepage rate is estimated at essentially zero, with no visible seepage.

Test Section T-2—The Klippel Flume is a 267-feet-long steel flume. The flume is built on a wooden trestle that crosses a small stream and valley. The Klippel flume carries the combines flows of the Bend and Tumalo Feed Canals. Before lining with Liquid Boot, this flume leaked significantly at the seams between 3-foot metal panels. Also, the metal itself was starting to corrode and had pinholes which were contributing to the seepage. The irrigation district routinely shoveled cinders into the flume to reduce the worst of the seepage. Water leaking from the flume would eventually end up in the small stream in the valley below. Pre-construction ponding tests were not performed; however, Tumalo Irrigation District personnel estimated the seepage at 0.5 cfs (200 gpm), which is equivalent to 15 ft/day (based on a length of 267 feet, and a wetted perimeter of 11 feet). The post-construction seepage rate is estimated at essentially zero, with no visible seepage.

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

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

Test Section L-1—The West Canal generally flows 70 to 80 days of the year. Earlier studies performed ponding tests over a 750 foot section and calculated a pre-construction seepage rate for the West Canal at 0.4 ft/day.[5] LAID personnel believe the seepage rate in the area of this test section is significantly higher because about 30 acres of adjacent farmland has been unusable because of seepage from the canal. Before lining, the irrigation district estimates that 6 to 10 acre-feet of water per day were lost to seepage over this 2,400-foot reach of canal. Based on a wetted perimeter of 23 feet, this equates to a seepage rate of 6.3 ft/day.

The irrigation district believes that the post-construction seepage rate is essentially zero over the ½-mile test section, because the year following installation of the test section, the 30 acres of land adjacent to the canal was returned to production for the first time in over a decade. A post-construction ponding test is planned for 1997.

[5] Bureau of Reclamation, September 1985; ECS Technical Services, July 1985.

CHAPTER V
CONCLUSIONS

Seepage.—Post-construction ponding tests show that lining canals can reduce short-term seepage rates by one to two orders of magnitude (90 to 99 percent). In general, shotcrete or concrete liners without a geomembrane liner reduce seepage by about one order of magnitude, while geomembrane liners, either with or without a concrete cover, typically reduce seepage by two orders of magnitude. However, seepage rates determined after 5 to 10 years of service will be more important than these short-term values.

Maintenance.—To date, the exposed geomembrane test sections have required more maintenance than the shotcrete-lined test sections. Many of the exposed geomembranes are in need of repairs at this time, and the irrigation districts typically do not have the equipment or expertise to perform the repairs. Therefore, Reclamation has purchased a hand-held thermal tack welder to assist the irrigation districts with these repairs. Cleaning debris and sediment from the exposed geomembrane test sections is expected to be more difficult and expensive than cleaning the shotcrete-lined sections.

Ice Jams.—Ice jams may interfere with winter water runs as seen on the Arnold Canal. These ice jams are an unforeseen consequence of lining the canals to reduce seepage. Greater control of canal slope during construction is needed to avoid this problem.

Shotcrete Thickness.—The 3-inch average shotcrete thickness is performing well. Actual thickness on the North Unit Canal ranges from less than 1 inch up to about 6 inches because of the irregular subgrade. The irrigation district has patched several small holes (6- to 24-inch diameter) where the shotcrete was very thin and broke away, but overall the irrigation district is quite pleased with the performance. In fact, the North Unit Irrigation District is soliciting proposals to concrete line the first 12 miles of canal invert from the North Dam to the silt pond. The District plans to monitor this section for seepage and then shotcrete the side slopes at a later date, if needed.

On the Arnold Canal, the shotcrete that is tapered to 1-inch thick over the anchor berms is showing extensive cracking, while the 3-inch shotcrete in the rest of the canal cross section is performing well. For future installations, the shotcrete should be maintained to a minimum thickness of 2 inches over the anchor berm.

Fibre Reinforcement.—To date, little to no difference has been detected between the performance of shotcrete with and without fibre reinforcement. In some cases, the fibre-reinforced shotcrete appears to have less cracking, but this may prove to be an isolated case and not a trend.

Reduced Freeboard.—Lining canals with 3 inches of shotcrete can significantly reduce the freeboard and flow capacity of the canal, especially when the subgrade conditions will not allow over-excavation. Available freeboard should be carefully evaluated in any future shotcrete lining applications.

Aesthetics.—Aesthetics was not a criteria when the lining systems were selected; however as the photographs show, some test sections look better than others. Aesthetics is by definition highly subjective; however, many observers find the shot-lined test sections more visually appealing than the exposed geomembranes.

Liquid Boot.—The Tumalo Irrigation District is quite pleased with the performance of the Liquid Boot spray-applied membrane and plans to line a third metal flume next year.

Performance.—At this point in the study, the test sections that are performing best are the geomembrane liners with a shotcrete or concrete cover. The geomembranes provide the lowest seepage rates, while the shotcrete cover protects the geomembrane from environmental and mechanical damage.

Cost Effectiveness.—Life-cycle costs and the cost of conserved water will be discussed in the next report.

CHAPTER VI
FUTURE STUDIES

New Test Sections.—Reclamation is collaborating with Mr. Terry Ackman of the U.S. Department of Energy - Pittsburgh Energy Technology Center (formerly of the Bureau of Mines) to identify high-loss reaches of the North Unit Canal using two geophysical techniques (terrain conductivity and very low frequency (VLF)). Other researchers have found that these techniques are effective for groundwater prospecting. Once identified, areas of high seepage could be sealed by injecting chemical grout into the subgrade rock on a 5- to 10-ft grid pattern to form a shallow impermeable barrier (approximately 3-feet deep) in the subsurface fractures directly beneath the canal prism. Sealing only the high-loss areas should prove quite cost effective compared to sealing the entire canal. To date, several surveys have been performed with various geophysical techniques and partially confirmed with ponding tests. Additional details on these promising techniques will be provided in a separate report.

Seepage Studies.—Ponding tests are planned on the Lugert-Altus Test Section for 1997 to determine the post-construction seepage rate. Additional ponding tests are planned on the North Unit and Arnold Test Sections for years 5 and 10 to determine long-term seepage rates. The 5-year ponding tests are scheduled for fall 1997 or spring 1998. Life-cycle costs and the cost of conserved water will be assessed at that time. The 10-year ponding tests are scheduled for 2002, followed by the final report.

Repairs.—The irrigation districts do not have the equipment or expertise to perform repairs on the exposed geomembrane test sections. Therefore, Reclamation has purchased a Novawelder GT-100 (hand-held thermal tack welder) for $2,000 to perform these repairs. In 1997, Reclamation will begin training the irrigation districts on the use of the Novawelder and will loan the equipment, as needed.

Durability Reports.—The next durability report will be published in the fall of 1999 to document visual inspections, performance, and maintenance costs after 7 to 8 years of service.

Final Report.—The final report is scheduled for publication in early 2003 (after year 10) and will provide long-term data on the design life, maintenance costs, life-cycle costs, seepage rates, and the cost of conserved water ($/acre-foot) for each test section.

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APPENDIX A

MATERIAL DATA SHEETS
TUMALO IRRIGATION DISTRICT

LIQUID BOOT®

LIQUID BOOT® PRIMARY USES

- Waterproof below grade floors and walls
- Methane gas barriers
- Radon gas barriers
- Irrigation canals, tanks and reservoir liners
- Landfill slope liners

ADVANTAGES OF LIQUID BOOT®

- Single course application
- Minimum equipment and manpower
- Fast Application
- Can be easily transported to remote areas
- Cost effective

CHARACTERISTICS OF LIQUID BOOT®

- Elastic - stretches 1300%
- 90% dimensional recovery
- Seamless - monolithic membrane
- Nonflammable
- Nontoxic
- Odorless
- Solvent free
- Applied at ambient temperature
- Sulfuric acid resistant
- Oil resistant
- Compatible with all geotextiles
- Adheres to most construction materials
- Low modulus - absorbs shock

LIQUID BOOT® PHYSICAL PROPERTIES

Elongation	ASTM D412	1,332% w/o reinforcement (90% Recovery)
Tensile Strength	ASTM D412	58 p.s.i. w/o reinforcement
Tensile Strength With 8 ounce Non-woven Geotextile both sides	ASTM D751	196 p.s.i. (Same as Geotextile tested separately)
Elongation With 8 ounce Non-woven Geotextile both sides	ASTM D751	100 % (Same as Geotextile tested separately)
Puncture Resistance With 8 ounce Non-woven Geotextile both sides	ASTM D4833	286 pounds (Travel of probe = 0.756 in.) (Same as Geotextile tested separately)
Hydrostatic Resistance (Burst) With 8 ounce Non-woven Geotextile both sides	ASTM D751	610 p.s.i. (Same as Geotextile tested separately)
Water Penetration Rate	ASTM D2434	<7.75 X 10^{-9} cm/sec
Water Vapor Permeability	ASTM E96	0.24 U.S. Perms
Water Vapor Transmission	ASTM E96	0.10 grains/h-ft^2
Methane Permeability	ASTM D1434	≤5.2 ml / day-m^2-atm
Radon Permeability	Tested by the U.S. Department of Energy	Zero Permeability to Radon (222 Rn)
Cold Bend Test	ASTM D146	Passed - No cracking @ -25°F
Freeze-Thaw Resistance (100 Cycles)	ASTM A742	Meets criteria - No spalling or disbondment
Accelerated Weathering and Ultraviolet Exposure	ASTM D822	No adverse affect after 500 hours
Acid Exposure (10% H_2SO_4 for 90 Days)	ASTM D543	Less than 1% change of weight
Oil Exposure (30 wt. for 28 days)	ASTM D543	Less than 1% change of weight
Electrical Volume Resistivity	ASTM D257	1.91 x 10^{10} ohms-cm
Health Effect as Drinking Water Component	ANSI/NSF 61	Meets requirements of NSF Standard 61
Toxicity Test	22 CCR 66696	Passed - CCR Bioassay-Flathead Minnow

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APPENDIX B

MATERIAL DATA SHEETS
LUGERT-ALTUS IRRIGATION DISTRICT

MATERIAL PROPERTIES

Teranap is a high performance puncture-resistant, polyester reinforced elastomeric bitumen geomembrane, lightly sanded on the one side and covered with a polyester film on the other side.

Property	Unit	Test Method	Teranap 331	Teranap 431
Thickness	mils	ASTM D5147	118	158
Specific Gravity	Density	ASTM D792	1.25	1.25
Weight	Pounds/ft^2	ASTM D5147	.76	.97
Dimensional Stability	Percent Change Each Direction	ASTM D1204	<1	<1
Low Temperature	°F	ASTM D746	Passes -40	Passes -40
Elongation Maximum Load (yield)	Percent	ASTM D5147	70	70
Elongation 5% Maximum Load	Percent	ASTM D5147	100	100
Tear Resistance	Pounds	ASTM D5147	90	96
Tensile MD	Pounds/Inch	ASTM D5147	100	110
Tensile XD	Pounds/Inch	ASTM D5147	75	92
Puncture Resistance	Pounds	FTMS 101 Method 2065	110	110
Creep Temperature	°F	Inclined on a 45° angle	≥160	≥160
Resistance to Soil Burial	Percent change in original value	ASTM D3083		
1. Breaking Factor			10	10
2. Elongation			10	10

These specifications are offered as a guide for consideration to assist engineers with their specifications; however Siplast assumes no liability in connection with the use of this information. The specifications on this data sheet are subject to change without notice.

Maintenance Costs
1995 and 1996
Tumalo Irrigation District

Test Section #	Maintenance Description	Cost
T-1	None	
T-2	Patched several blister with Roofing Tar	$200
T-3	None	

Maintenance Costs
Lugert-Altus Irrigation District
1996

Test Section #	Maintenance Description	Cost
L-1	Repaired rainstorm wash-out	$3,000

Mission

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