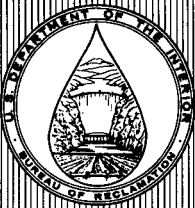


R-94-14



# **DESCHUTES—CANAL-LINING DEMONSTRATION PROJECT DURABILITY REPORT—YEAR 2**

September 1994

**U.S. DEPARTMENT OF THE INTERIOR**  
Bureau of Reclamation

Technical Service Center  
Research and Laboratory Services Division  
Materials Engineering Branch

Pacific Northwest Regional Office  
Planning Program and Development Office

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**DESCHUTES—CANAL-LINING  
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**by**

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September 1994

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Reclamation also acknowledges 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.

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## SUMMARY

Eighteen canal-lining test sections were constructed in central Oregon to assess their effectiveness at reducing seepage and durability over severe rocky subgrade conditions. The lining materials included combinations of geosynthetics, concrete grout, shotcrete, elastomeric coatings, and sprayed-in-place foam. Those 18 test sections are now 2 years old. The test sections have been visually inspected every 6 months, and careful maintenance records have been kept.

After only two years of service, obvious differences in the performance of the 18 test sections are becoming apparent. The two exposed coated geotextile test sections have washed out completely; the two sprayed-in-place polyurethane foam test sections have partially washed out and need extensive repairs; and the two exposed geomembrane test sections with grout-filled mattresses on the side slopes are experiencing uplift pressures and are in danger of failure. The other 12 test sections (consisting of shotcrete, grout-filled mattresses, or exposed geomembranes) are all in very good to excellent condition.

Some test sections are in need of minor repairs at this time. If not repaired promptly, these minor problems may develop into major problems requiring expensive repairs, and may even lead to premature failure.

The irrigation districts have performed some minor repairs on the shotcrete test sections. They have not performed repairs on the exposed geomembrane test sections because they do not have some of the special equipment and qualifications to make the repairs required. Therefore, for this program to succeed, the irrigation districts need training and access to equipment to make geomembrane repairs.

## INTRODUCTION

This report is the second in a series of reports covering the Deschutes Canal Lining Demonstration Project. The demonstration project supports the UDRBWCP (Upper Deschutes River Basin Water Conservation Project) study, a cooperative effort among the Reclamation (Bureau of Reclamation), the Oregon Water Resources Department, and 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.

The first report "Deschutes - Construction Report" (Reclamation Report R-94-06, 1994) documented the construction of 18 test sections on the Arnold and North Unit Canals near Bend, Oregon. The construction report detailed construction techniques, construction materials, unit construction costs, and ponding tests to determine seepage rates both before and after construction of the test sections. Post-construction seepage rates were 10 to 100 times lower than pre-construction rates. The lining materials included combinations of geosynthetics, concrete grout, shotcrete, elastomeric coatings, and sprayed-in-place foam. Figure 1 shows the location of the Arnold and North Unit Canals. Figures 2 and 3 show the location of each of the 18 test sections. Table 1 summarizes the original unit construction costs for each test section.

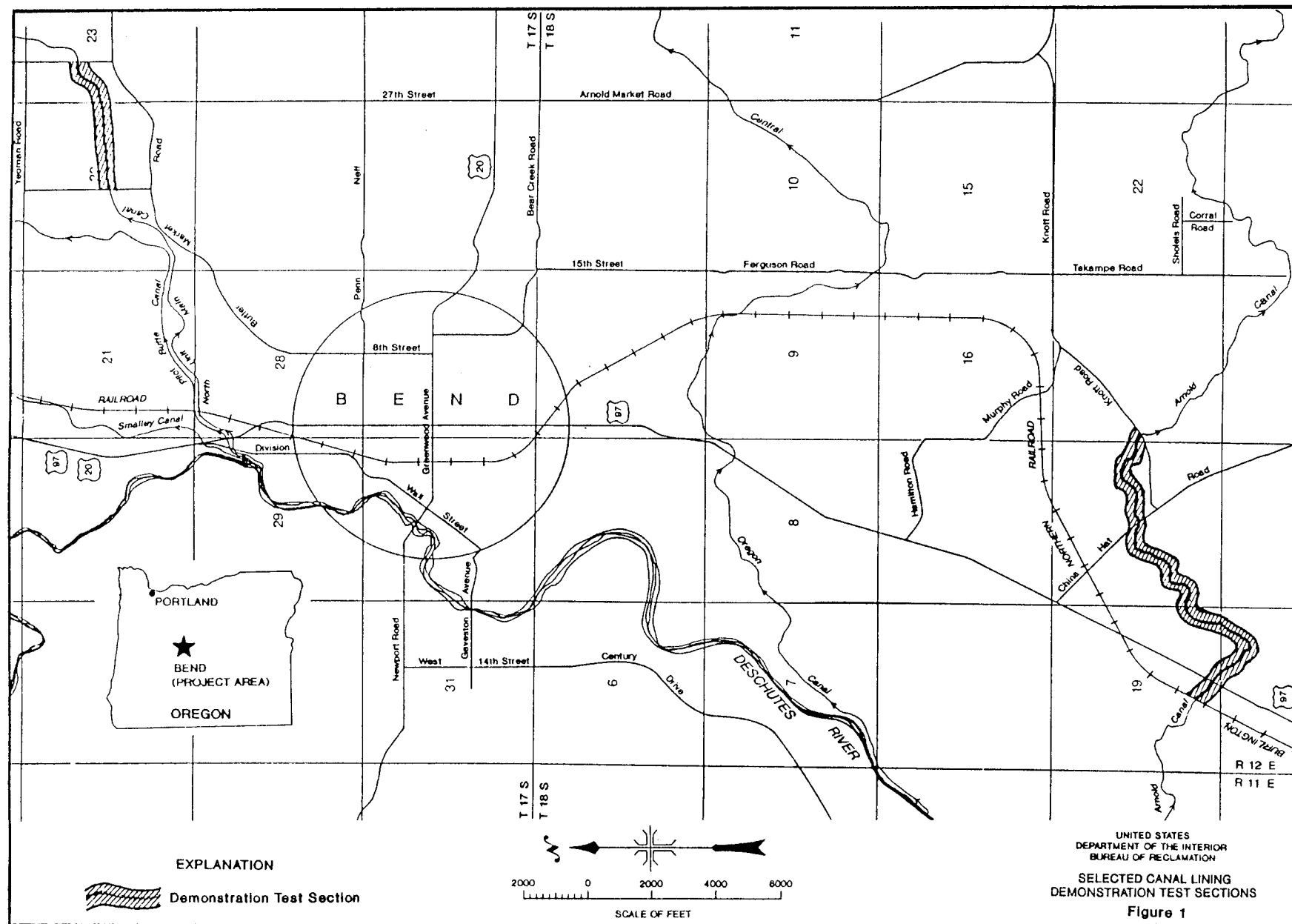


Figure 1. - Location of demonstration project test sections.

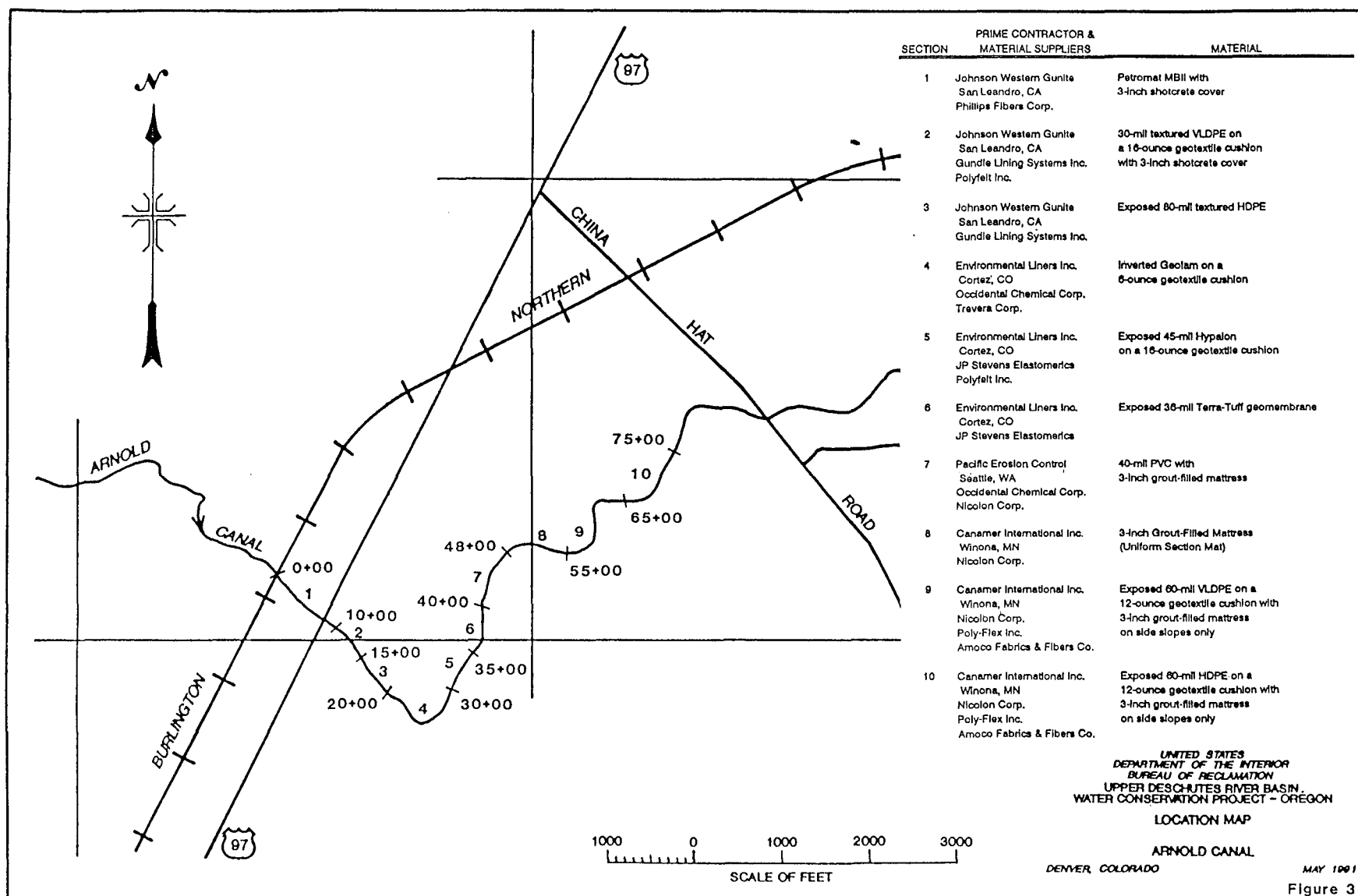


Figure 3

Figure 2. - Arnold Canal location map.

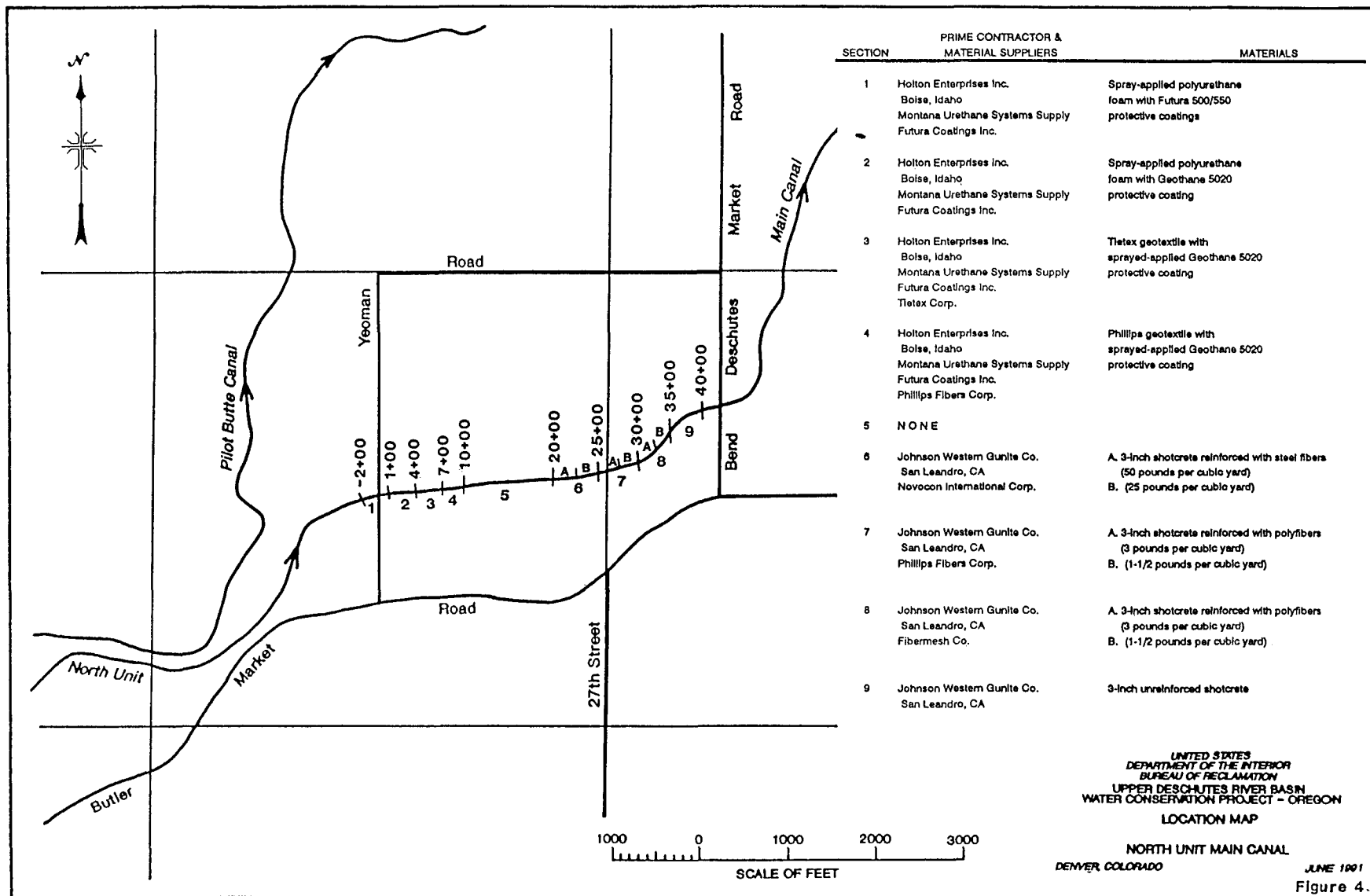


Figure 3. - North Unit Main Canal location map.

Table 1. - Comparison of canal lining costs.

Section No.	Arnold Irrigation District Description	Lining Material					Subgrade Preparation Cost per sq. foot	Installation Cost per sq. foot	Overhead and Profit %	Total \$
		Geomembrane Cost per sq. foot	Geotextile Cost per sq. foot	Shotcrete Cost per sq. foot	Other Cost per sq. foot	Total Cost per sq. foot				
		\$	\$	\$	\$	\$	\$	\$	%	\$
1	Petromat MB II with 3-in. Shotcrete cover									
	Unreinforced Shotcrete	\$0.30		\$0.65		\$0.95	\$0.26	\$0.55	17%	\$2.06
	1-1/2 lbs. per cubic yard	\$0.30		\$0.65	\$0.05	\$1.00	\$0.26	\$0.55	17%	\$2.12
2	30-mil VLDPE textured geomembrane with 3-in. unreinforced Shotcrete cover and 16-oz. geotextile cushion	\$0.25	\$0.12	\$0.65		\$1.02	\$0.26	\$0.55	17%	\$2.14
3	80-mil HDPE textured geomembrane	\$0.70	\$0.12			\$0.82	\$0.26	\$0.10	17%	\$1.38
4	Geolam with 6-oz. geotextile cushion	\$0.45	\$0.07			\$0.52	\$0.26	\$0.12	17%	\$1.05
5	45-mil Hypalon with 16-oz. geotextile cushion	\$0.45	\$0.12			\$0.57	\$0.26	\$0.12	17%	\$1.11
6	TerraTuff (36-mil Hypalon/8-oz. geotextile)	\$0.50				\$0.50	\$0.26	\$0.12	17%	\$1.03
7	40-mil PVC with 3-in. Grout-Filled mattress	\$0.35		\$0.65	\$0.45	\$1.45	\$0.12	\$0.45	17%	\$2.36
8	3-in. Unreinforced Grout-Filled Mattress			\$0.65	\$0.45	\$1.10	\$0.04	\$0.45	17%	\$1.86
9 & 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	\$1.04	\$0.04	\$0.45	17%	\$1.79
North Unit Irrigation District										
Section No.	Description									
1	Spray-applied Polyurethane Foam base with Urethane 500/550 protective coating				\$2.41	\$2.41	\$0.04	\$1.25	17%	\$4.33
2	Spray-applied Polyurethane Foam base with Geothane 5020 protective coating				\$2.06	\$2.06	\$0.04	\$1.25	17%	\$3.92
3	Tietex Geotextile with Spray-applied Geothane 5020 protective coating		\$0.07		\$0.90	\$0.97	\$0.04	\$1.25	17%	\$2.64
4	Phillips Geotextile with Spray-applied Geothane 5020 protective coating		\$0.07		\$0.90	\$0.97	\$0.04	\$1.25	17%	\$2.64
6	3-in. Steel-Fiber Reinforced Shotcrete									
	50 lbs. per cubic yard			\$0.65	\$0.22	\$0.87	\$0.04	\$0.45	17%	\$1.59
	25 lbs. per cubic yard			\$0.65	\$0.09	\$0.74	\$0.04	\$0.45	17%	\$1.44
7 & 8	3-in. Polyfiber Reinforced Shotcrete									
	3 lbs. per cubic yard			\$0.65	\$0.12	\$0.77	\$0.04	\$0.45	17%	\$1.47
	1-1/2 lbs. per cubic yard			\$0.65	\$0.05	\$0.70	\$0.04	\$0.45	17%	\$1.39
9	3-in. Unreinforced Shotcrete			\$0.65		\$0.65	\$0.04	\$0.45	17%	\$1.33

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

This second report assesses the condition of the 18 test sections after about 2 years (13 to 29 months) of service through April 1994. Required maintenance and maintenance costs are also reported.

Future reports will document the construction of additional test sections (Siplast and Liquid Boot installations are scheduled for 1994) and assess the condition of all the test sections for a period of 10 years, including additional ponding tests scheduled for years 5 and 10. The final report is scheduled for publication in 2003 (year 10). That final report will provide long-term data on the design life, maintenance costs, life-cycle costs, long-term seepage losses, and the cost (\$/acre-ft) of conserved water for each test section.

## CONCLUSIONS

1. After two years of service, differences between the 18 test sections are becoming apparent. Two test sections have washed out completely, two test sections have partially washed out, and two test sections are experiencing uplift pressures and are in danger of failing this irrigation season. The remaining 12 test sections are in excellent condition.

2. Many test sections are in need of minor repairs at this time. If not repaired promptly, these minor problems may develop into major problems, and may lead to premature failure. Insufficient time was available to perform these repairs before the 1994 irrigation season. Hopefully, the present level of damage will not cause any problems during the 1994 irrigation season. The need to perform minor repairs either in fall 1994 or spring 1995 before water is turned back on is essential.

3. The more expensive liners were North Unit test sections 1, 2, 3, and 4 (spray polyurethane foam and coated geotextile). Construction costs for these four test sections ranged from \$2.64 to \$4.33 per square foot. Surprisingly, these more expensive test sections failed first. The unit construction costs for the remaining liners are between \$1.05 to \$2.36 per square foot.

4. The Arnold Irrigation District needs some special materials, equipment, and training for performing present and future repairs to exposed geomembrane liners. The following materials are needed.

- Hot wedge welder and materials to patch HDPE and VLDPE in test sections 3, 9, and 10.
- PVC (polyvinyl chloride) patching kit, including solvent cement and a supply of Geolam membrane.
- Hypalon patching kit, including appropriate solvent cement and a supply of 36-mil or 45-mil Hypalon geomembrane.

5. To date, exposed geomembrane liners have required more maintenance than shotcrete liners. Exposed geomembranes easily float if water gets behind them (which is what happened to North Unit test sections 3 and 4) because they are not anchored. These results indicate that exposed geomembranes should be inspected and repaired annually.

6. Aesthetics was not a criteria when the lining systems were selected; however, as the photographs show, some test sections look better than others.



## CONDITION ASSESSMENT

### Visual Inspections

The 18 test sections were constructed between November 1991 and March 1993, and are now all 1 to 2 years old (13 to 29 months). Since construction, semi-annual visual inspections have been performed to monitor lining condition, assess durability, and evaluate any maintenance requirements. Visual inspections were performed in October 1992, April 1993, November 1993, and April 1994. The condition of each test section is summarized in Tables 2 and 3.

Some of the test sections have either partially or totally failed. For this study, a test section liner is considered partially failed when a significant portion of the test section no longer provides seepage control. Total failure occurs when the liner has completely washed out, or when it has deteriorated to the point that it provides essentially zero water savings (i.e., the seepage rate is equivalent to the rate measured prior to installation of the liner).

Table 2. - Two-year condition assessment - Arnold Canal.

#	Test Section	Condition	Comments
1	Petromat with 3-inch Shotcrete cover	Excellent	No problems
2	30-mil VLDPE with 3-inch Shotcrete cover	Excellent	No problems
3	Exposed 80-mil HDPE	Very good to Excellent	2 or 3 small tears in geomembrane
4	Exposed Geolam	Excellent	Dirt collecting in geotextile seams
5	Exposed 45-mil Hypalon	Excellent	No problems
6	Exposed 36-mil Terra-Tuff	Very good to Excellent	Cuts in geomembrane at downstream dike
7	40-mil PVC with 3-inch grout-filled mattress	Excellent	No problems
8	3-inch grout-filled mattress	Excellent	No problems
9	Exposed VLDPE with grout-filled mattress on side slopes only	Marginal	Numerous tears in exposed VLDPE; Liner "whales" restricting flow
10	Exposed HDPE with grout-filled mattress on side slopes only	Marginal	Few tears in exposed HDPE; Liner "whales" restricting flow

Table 3. - Two-year condition assessment - North Unit Main Canal.

#	Test Section	Condition	Comments
1	SPF with Futura 500/550 protective coating	Partially failed	Partial foam wash-out; Will not repair at this time; Monitor only
2	SPF with Geothane 5020 protective coating	Partially failed	Partial foam wash-out; Will not repair at this time; Monitor only
3	Tietex Geotextile with Geothane 5020 coating	Failed	Minor repairs (March 93) Failed completely (May 93) Removed remaining lining
4	Phillips Geotextile with Geothane 5020 coating	Failed	Minor repairs (March 93) Failed completely (May 93) Removed remaining lining
6	3-inch shotcrete with Novocon steel fibers	Excellent	Area of unstable imported subgrade fill on left bank has required some minor maintenance
7	3-inch Shotcrete with Phillips Polyfibers	Excellent	No problems
8	3-inch Shotcrete with Fibermesh Polyfibers	Excellent	No problems
9	3-inch unreinforced Shotcrete	Excellent	No problems

## Maintenance Reports

The Arnold and North Unit Irrigation Districts have been documenting all maintenance activities for this demonstration project. For each of the 18 test sections, the irrigation districts have been completing annual maintenance data sheets developed by Reclamation. The maintenance data sheets provide a narrative description of all maintenance activities, as well as cost break-downs for materials, labor, and equipment. The maintenance data sheets are included in appendixes A (Arnold Canal) and B (North Unit Main Canal). Maintenance activities and costs to date for each test section are summarized in tables 4 and 5. However, the tabulated maintenance costs are not necessarily indicative of test section performance. Many test sections are in need of repairs that have not been performed to date. If these repairs are not performed in a timely manner, additional more extensive repairs will be needed in the future.

Table 4. - Maintenance costs - Arnold Canal.

#	Test Section	Maintenance Requirements	Maintenance Performed		Additional Maintenance Needed
			Description	Cost (\$)	
1	Petromat with 3-inch Shotcrete cover	None	None	0	None
2	30-mil VLDPE with 3-inch Shotcrete cover	None	None	0	None
3	Exposed 80-mil HDPE	Minimal	None	0	Patch 2 or 3 small tears
4	Exposed Geolam	Minimal	Contractor sewed several geotextile seams above the waterline	0*	Sew remaining geotextile seams
5	Exposed 45-mil Hypalon	None	None	0	None
6	Exposed 36-mil Terra-Tuff	Minimal	None	0	Patch cuts in liner at dike
7	40-mil PVC with 3-inch grout-filled mattress	None	None	0	None
8	3-inch grout-filled mattress	None	None	0	None
9	Exposed VLDPE with grout-filled mattress on side slopes only	Extensive	None	0	Patch tears in exposed VLDPE; Ballast invert to prevent uplift
10	Exposed HDPE with grout-filled mattress on side slopes only	Extensive	Removed portland cement deposits in invert	\$320	Remove remaining portland cement; Patch minor tears in exposed HDPE; Ballast invert to prevent uplift

\* Cost of sewing geotextile seams is part of construction costs.

Table 5. - Maintenance Costs - North Unit Main Canal.

#	Test Section	Maintenance Requirements	Maintenance Performed		Additional Maintenance Needed
			Description	Cost (\$)	
1	SPF with Futura 500/550 protective coating	Extensive	Removed washed-out foam at Siphon; Installed weed rack at Siphon	1387 240 \$ 1627	Needs extensive foam and coating repairs; will not repair at this time; monitor only
2	SPF with Geothane 5020 protective coating	Extensive	Removed washed-out foam at Siphon; Installed weed rack at Siphon	1387 240 \$ 1627	Needs extensive foam and coating repairs; will not repair at this time; monitor only
3	Tietex Geotextile with Geothane 5020 protective coating	Extensive	Patched holes in geotextile lining; Removed washed-out geotextile lining; Repaired damaged COI Pipe crossing	555 1387 803 \$ 2745	None - complete failure; lining removed
4	Phillips Geotextile with Geothane 5020 protective coating	Extensive	Patched geotextile lining; Removed washed-out geotextile lining; Repaired damaged COI pipe crossing	555 1387 803 \$ 2745	None - complete failure; lining removed
6	3-inch Shotcrete with Novocon Steel Fibers	Minor	Patched hole, removed large rocks; Patched second hole in Shotcrete	835 142 \$ 977	None
7	3-inch Shotcrete with Phillips Polyfibers	None	None	0	None
8	3-inch Shotcrete with Fibermesh Polyfibers	None	None	0	None
9	3-inch unreinforced Shotcrete	None	None	0	None

## DURABILITY

### Arnold Canal

#### *Test Section 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 (26 months old)

**Location:** Station 0+00 to 10+00 (1,000 linear feet; 30,000 square feet)

**Condition:** Excellent - the shotcrete lining is in excellent condition, completely protecting the underlying Petromat geosynthetic liner from weathering and mechanical damage. After two winters, no freeze-thaw damage has been observed. Several (perhaps a dozen) transverse contraction cracks have developed, ranging in width from hairline up to about 1/8 inch. The cracks are mostly in the sidewalls and do not usually extend into the invert. Also, one longitudinal crack on the side slope was discovered. The first 500-foot section contains 1½ lb/yd<sup>3</sup> polyfiber reinforcement and has a similar cracking pattern to the second 500-foot section without fiber reinforcement. These transverse and longitudinal shotcrete cracks are not considered detrimental because the Petromat geomembrane underliner provides the seepage control, and the shotcrete cover protects the geomembrane from weathering, ultraviolet light, mechanical damage, vandalism, and animal damage. The shotcrete has developed some minor random cracking over the anchor trench where the shotcrete tapers off. Sediment in the majority of the invert is less than 1/8 inch deep. However, on one curve the sediment is about 3 inches deep.

In March 1994, about 100 linear feet of this test section was torn-out and replaced when the Highway 97 bridge at station 7+00 (estimated) was widened from two lanes to four. The new replacement lining uses the same construction materials and techniques as the old lining (Petromat with 3-inch shotcrete cover). Costs for this lining replacement will not be included in either the initial construction costs or in the maintenance costs.

**Maintenance:** No maintenance requirements to date

Performed: None

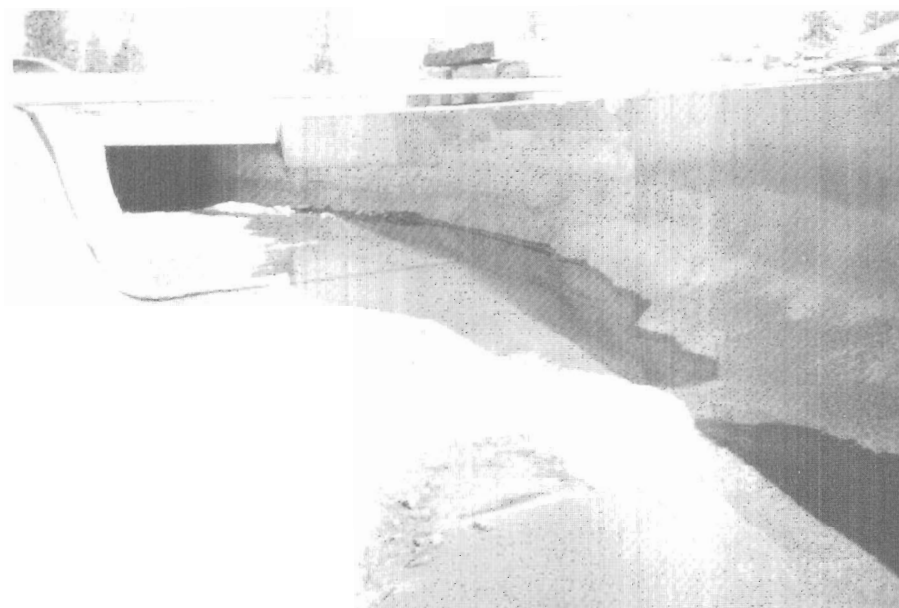
Needed: None—no specialized equipment or training required

**Photographs:** 1 through 4

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



Photograph 1. - Canal overview—excellent condition.



Photograph 2. - About 100 linear feet of shotcrete and Petromat lining were replaced in March 1994 when the highway bridge was widened.

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



Photograph 3. - Transverse contraction crack in shotcrete lining.



Photograph 4. - Longitudinal contraction crack in shotcrete lining.

***Test Section 2.—***

Material: 30-mil textured VLDPE with 16-ounce geotextile cushion and 3-inch shotcrete cover

Description: VLDPE liner is 30-mil Gundle textured Hyperlastic. 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 (18 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 two winters, no freeze-thaw damage has been observed. A few transverse contraction cracks and one longitudinal crack have developed on the sidewalls. The transverse crack at station 13+00 (estimated) extends completely across the canal prism and measures about 3/16 inch wide. Cracking in the thin, tapered shotcrete over the anchor trench is slightly more severe than on test section 1, but is not a problem at this time. Little to no sediment has collected in the canal invert.

Maintenance: No maintenance requirements to date

Performed: None

Needed: None—no specialized equipment or training required

Photographs: 5 through 10



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

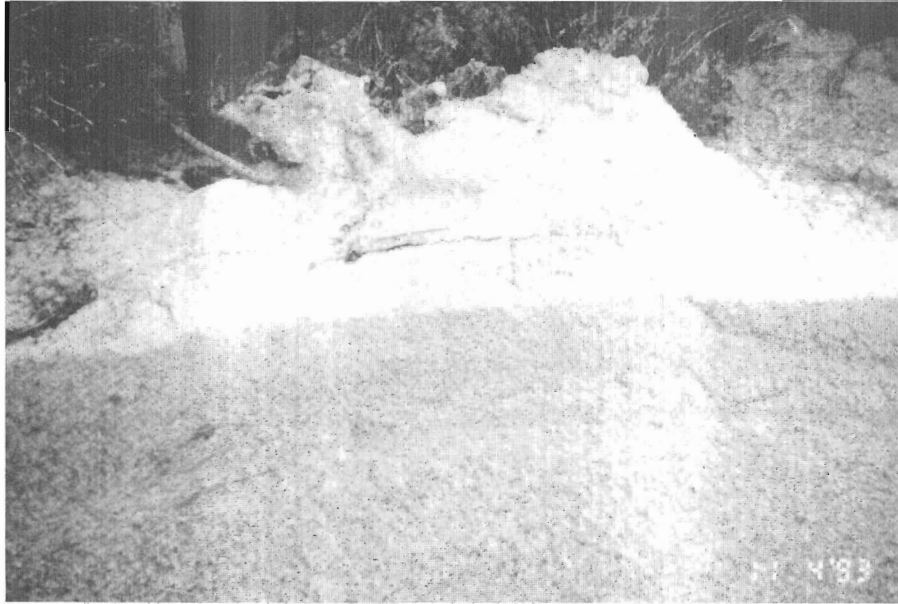


Photograph 5. - Canal overview—excellent condition.



Photograph 6. - Tapered shotcrete over anchor trench has been damaged (cracked) by foot traffic.

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

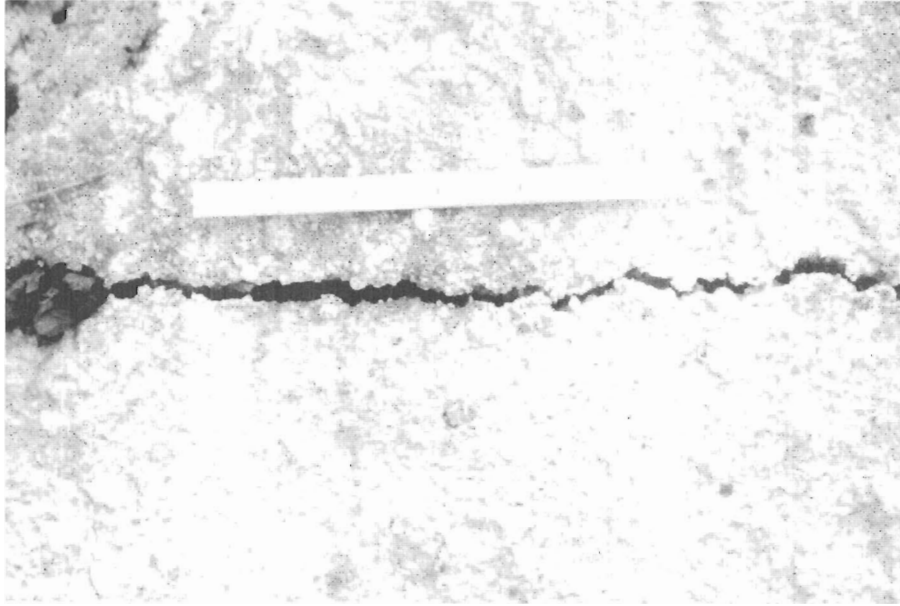


Photograph 7. - Longitudinal contraction crack just above the waterline.

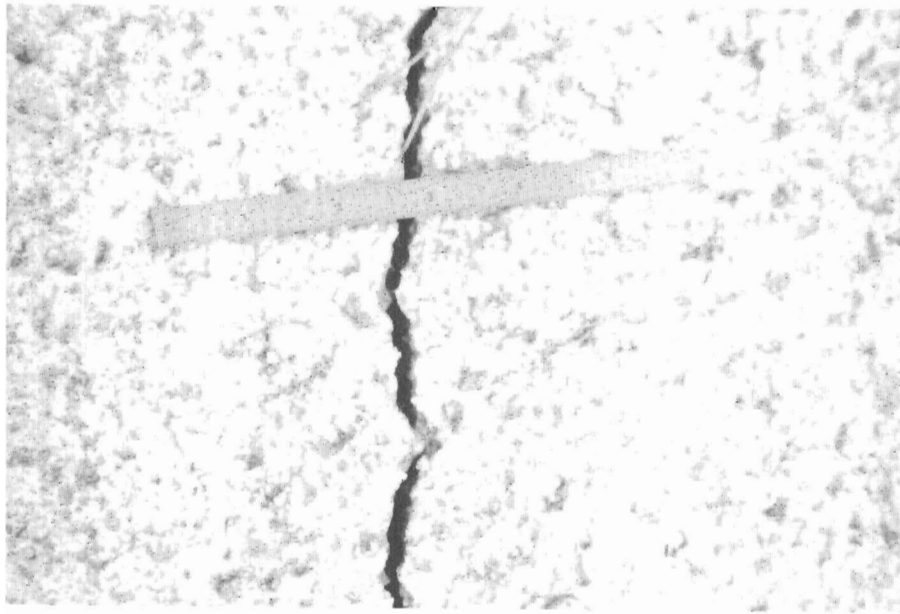


Photograph 8. - Transverse contraction crack.

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



Photograph 9. - Close-up of longitudinal contraction crack.



Photograph 10. - Close-up of transverse contraction crack.

### ***Test Section 3.—***

Material: Exposed 80-mil textured HDPE

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

Construction Cost: \$1.38 per square foot

Date Installed: October 1992 (18 months old)

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

Condition: Very Good to Excellent - the exposed HDPE liner is in excellent condition. Longitudinal wrinkles from excess slack are apparent throughout. A semicircular tear (thought to be from an animal hoof) was found on the left bank above the water line about 75 feet downstream from the bridge. Little to no sediment has collected in the canal invert. The rock fill in the anchor trenches is performing well. Very little freeboard is available on the right bank; however, the extra HDPE in the anchor trench is sufficient to increase the freeboard if needed. At station 19+80 (estimated), the HDPE is stretched very tightly over a rock, and this area will be monitored for future potential puncture. A small tear at the upstream end (station 15+00 estimated) is believed to be caused from backhoe operation during dike construction for post-construction ponding tests.

Below the waterline, the HDPE liner is covered with a thin, dry film possessing a myriad of very faint colors (blues, greens, yellows, pinks and purples). Any materials leaching from the liner are expected to be waxy or clear in color. Therefore, this dry colored film is believed to be some type of algae growth, which should not have any adverse effect on the liner performance.

Maintenance: Minimal maintenance required to date

Performed: None

Needed: Patch two or three small tears in the liner.  
To perform repairs, irrigation district needs an extrusion welder, extra membrane, and specialized training.

Photographs: 11 through 14

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

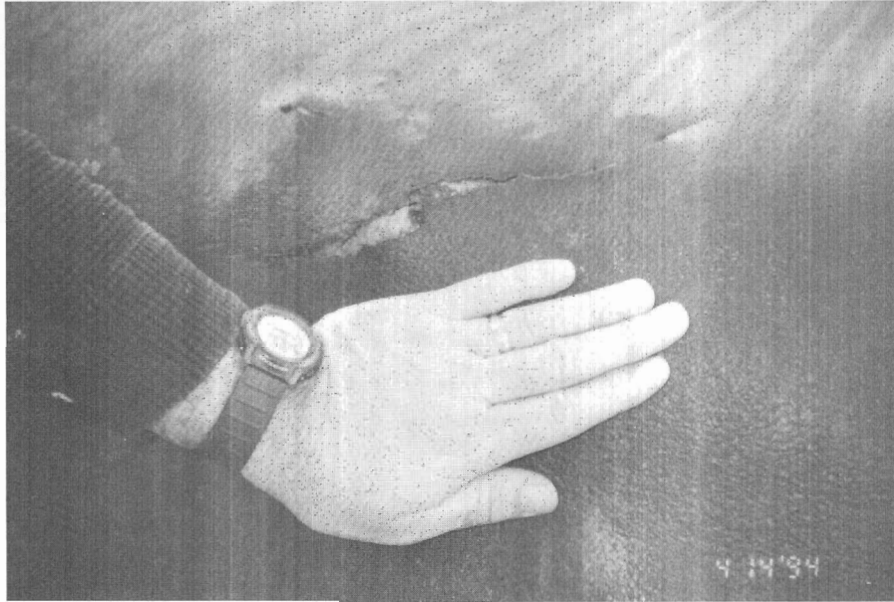


Photograph 11.- Canal overview-excellent condition.



Photograph 12. - Suspected animal hoof damage.

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



Photograph 13. - Tear from sharp subgrade rocks.



Photograph 14. - Backhoe damage at upstream dike.

#### ***Test Section 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 (25 months old)

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

**Condition:** Excellent - actually performing much better than expected. The exposed geotextile is collecting dirt. About 1 inch of sediment has collected in the canal invert, which is actually beneficial because the sediment anchors the exposed geomembrane and provides UV protection. The geotextile is in good condition with little deterioration to date. "Scuffing" of the geotextile along the top of each berm is probably caused by animals or workers entering and exiting the canal. Many of the geotextile seams still need to be sewn. As photo 17 shows, hog-rings have not been effective for seaming the geotextile except where spaced very closely (every 6 inches). Many unsewn seams beneath the waterline are filled with sediment, which is forcing open the unseamed sections further. Where the PVC geomembrane is exposed on the sides of the canal, it has turned white in color. Any exposed PVC beneath the waterline remains a gray color. This color change may be a sign of deterioration. The integrity of the geotextile cover is essential for protection of the PVC geomembrane from UV light.

The subgrade is quite rough, and a number of pointed rock stress concentrations can be seen in the geomembrane. No tearing has been observed in the geomembrane or geotextile cushion. The seams in the geomembrane and the sewn seams in the geotextile are holding up well. Although many wrinkles in the geomembrane were evident (probably because the canal curves in this section), they have posed no problems.

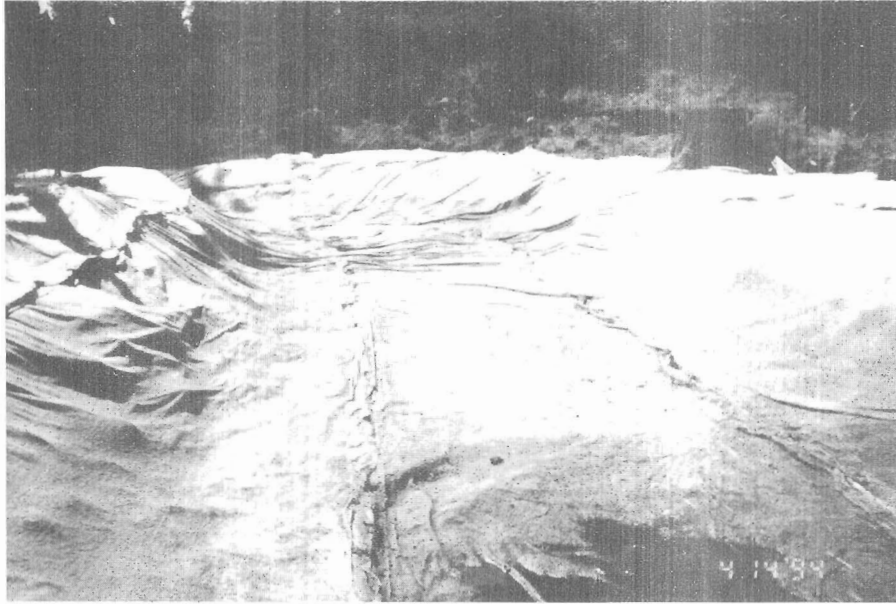
**Maintenance:** Minimal maintenance required to date

**Performed:** Contractor came back and sewed several geotextile seams above the waterline. Those costs are considered part of initial construction costs and not maintenance costs.

**Needed:** Additional geotextile seams need to be sewn, hog-ringed, or glued to protect PVC geomembrane from degradation caused by UV light exposure. To perform future repairs to the geomembrane, the irrigation district needs PVC solvent cement, extra Geolam, and specialized training.

**Photographs:** 15 through 20

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



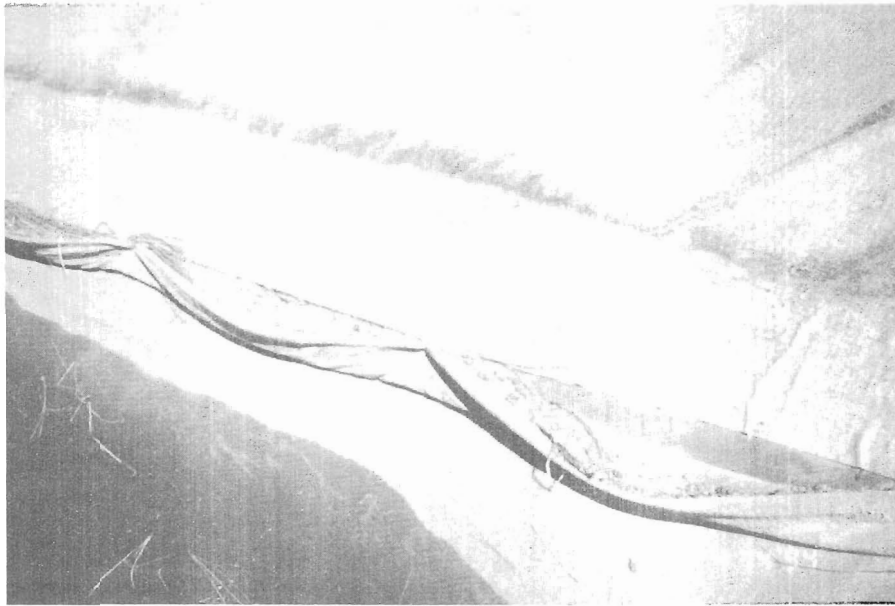
Photograph 15. - Canal overview—excellent condition.



Photograph 16. - Close-up of sewn geotextile seam.



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



Photograph 17. - PVC geomembrane is exposed where sediment has collected in hog-ringed geotextile seams.

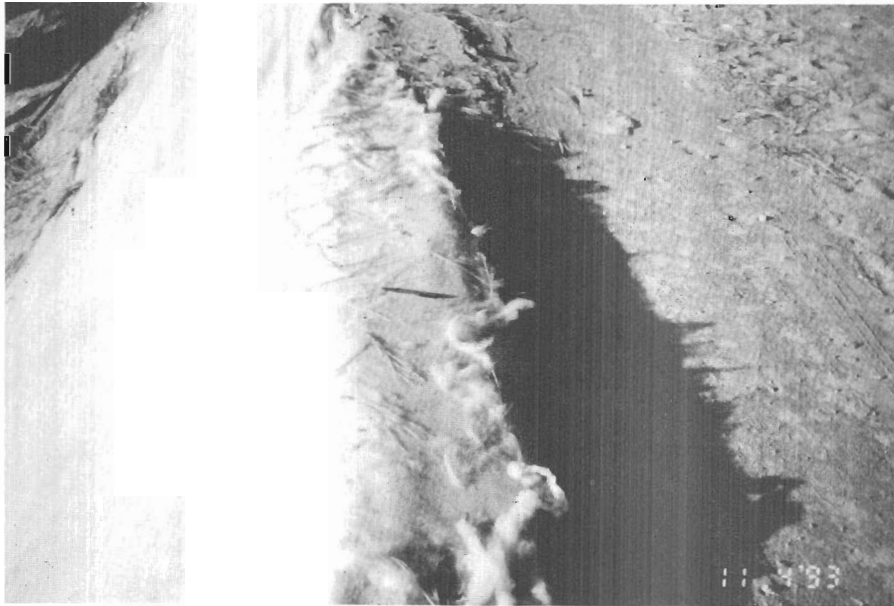


Photograph 18. - Dirt and sediment collecting on geotextile provides additional UV protection.

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



Photograph 19. - Contractor sewing geotextile seams.



Photograph 20. - "Scuffing" of geotextile along bank, possibly where animals or workers enter and exit the canal.

***Test Section 5.—***

Material: Exposed 45-mil Hypalon with 16-ounce geotextile cushion

Description: The Hypalon membrane is JP Stevens 45-mil reinforced CSPE (chlorosulfonated polyethylene). The geotextile cushion is Polyfelt TS-1000, a 16-ounce, needle-punched, non-woven geotextile.

Construction Cost: \$1.11 per square foot

Date Installed: March 1992 (25 months old)

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

Condition: Excellent - the exposed Hypalon geomembrane is holding up well. No damage or tears have been observed to date. Again, colored algae film is visible below the waterline.

The majority of the canal has less than 1 inch of sediment in the invert, but some areas have as much as 4 inches. Very few wrinkles were observed in the lining.

Maintenance: No maintenance required to date

Performed: None

Needed: None—to perform future repairs to the geomembrane, the irrigation district needs Hypalon solvent cement, extra Hypalon, and specialized training.

Photographs: 21 through 24

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

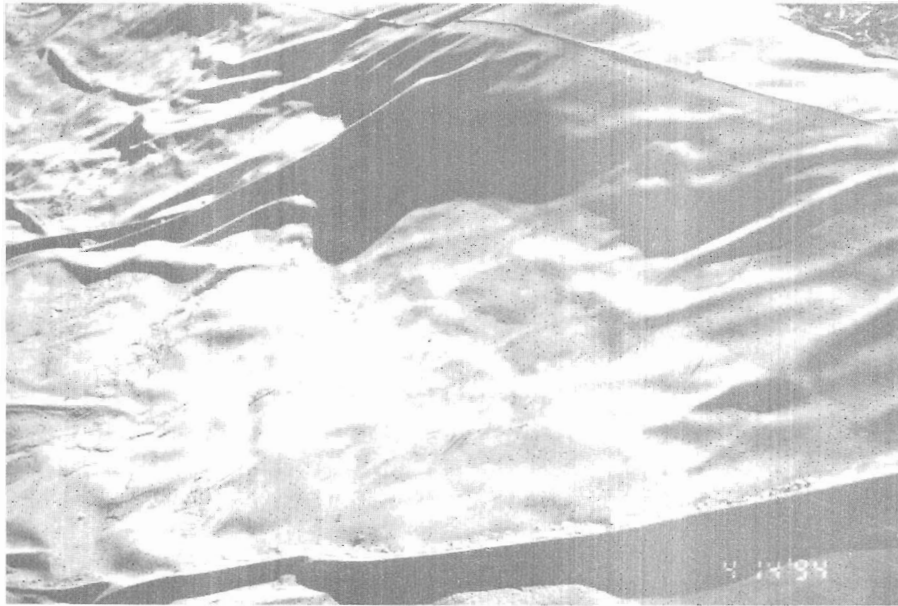


Photograph 21. - Canal overview—excellent condition.



Photograph 22. - Colored algae growing below water line.

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



Photograph 23. - Wrinkles in exposed geomembrane provide slack for thermal expansion and contraction.



Photograph 24. - Canal in service.

***Test Section 6.—***

Material: Exposed 36-mil Terra-Tuff

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

Construction Cost: \$1.03 per square foot

Date Installed: March 1992 (25 months old)

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

Condition: Very Good to Excellent - The exposed Hypalon geomembrane is holding up well. Less than 1 inch of silt has collected in the invert. A few wrinkles are present to provide slack for thermal expansion and contraction. Again, colored algae dry film is visible below the waterline. At station 40+00, this Terra-Tuff liner is connected to the downstream grout-filled mattress by batten strips, which are holding up well.

This test section was placed into service before the upstream test section was completed. The upstream cut-off trench was not yet constructed, and water was able to get behind (under) this Hypalon liner. At station 39+90 (estimated), the irrigation district made several large cuts in the Hypalon liner to relieve the trapped water pressure. These cuts should be repaired to prevent additional water from getting behind the liner.

Maintenance: Minimal maintenance required to date

Performed: None

Needed: Repair cuts in liner at station 39+90.  
To perform future repairs to the geomembrane, the irrigation district needs Hypalon solvent cement, extra Hypalon, and specialized training.

Photographs: 25 through 28

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

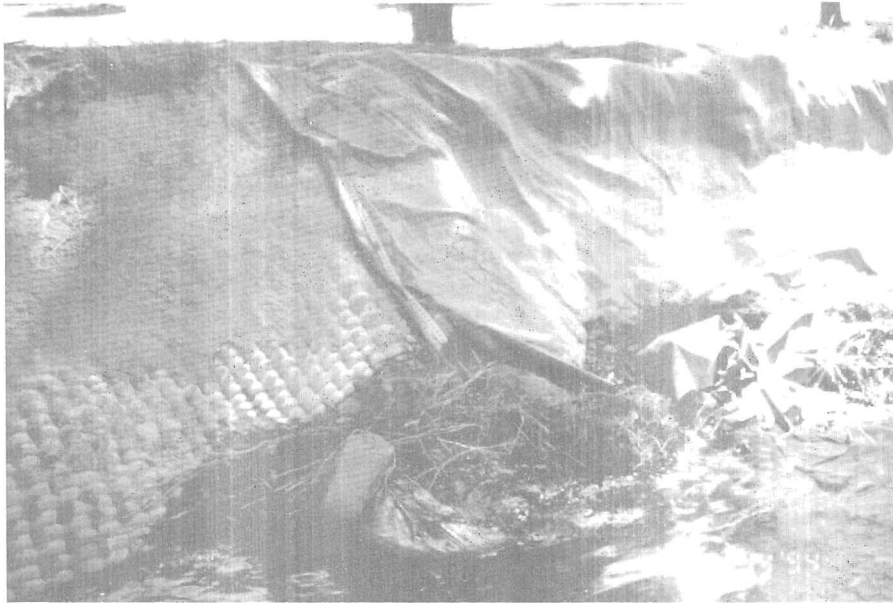


Photograph 25. - Canal overview—excellent condition.



Photograph 26. - Cuts in geomembrane in invert at downstream dike need to be repaired.

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



Photograph 27. - Damage at downstream dike.



Photograph 28. - Batten strip ties exposed Hypalon into grout mattress in adjoining test section.



***Test Section 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 (29 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, protecting the underlying PVC geomembrane. No freeze-thaw damage has been observed. The mattress is uniformly grouted in spite of the uneven rocky subgrade. A minute amount of cement paste is present in the invert between the concrete "bricks." Little to no sediment is present in the invert, except on one curve, where about a foot of silty sediment has been deposited. The outer fabric of the grout mattress is in good condition with little to no deterioration to date. On two inspection trips, test section 7 contained more standing water than test section 8, suggesting that the PVC liner may be reducing the seepage rate.

Maintenance: No maintenance required to date

Performed: None

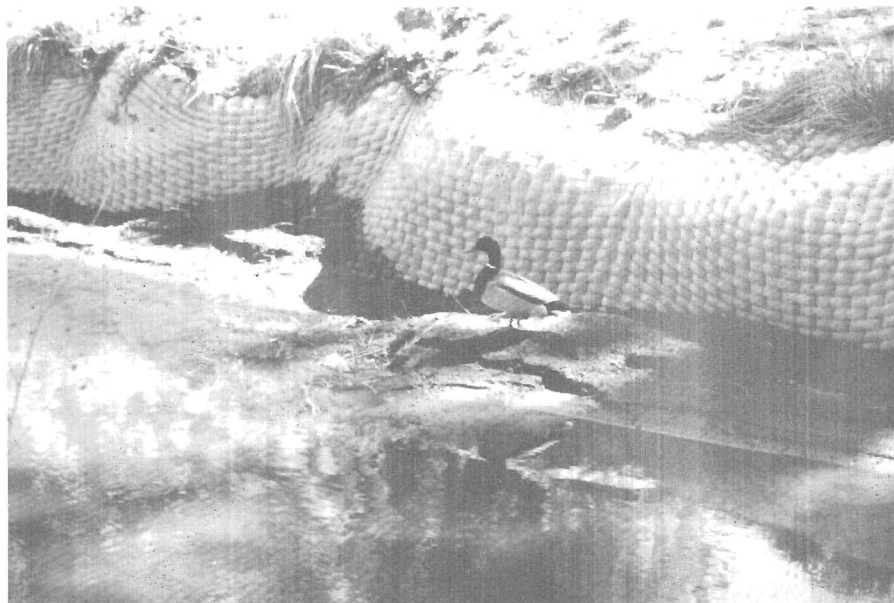
Needed: None—no specialized equipment or training required

Photographs: 29 through 30

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



Photograph 29. - Canal overview—excellent condition.



Photograph 30. - Standing water in this test section is used as a watering hole by local wildlife.

***Test Section 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)  
(17 and 29 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. No freeze-thaw damage has been observed. The mattress is uniformly grouted in spite of the uneven rocky subgrade. A small amount of cement paste is present in the invert between the concrete "bricks" (see photo). Little to no sediment is present in the invert. The outer fabric of the grout mattress is in good condition with no noticeable deterioration to date.

Maintenance: No maintenance required to date

Performed: None

Needed: None—no specialized training or equipment needed.

Photographs: 31 through 32

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



Photograph 31. - Canal overview—excellent condition.



Photograph 32. - Small amount of cement paste oozed through the mattress during pumping.

### ***Test Section 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 (17 months old)

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

**Condition:** Marginal - lots of damage (mostly man-made). Gas bubbles (possibly volcanic in origin) developed in the invert under the liner when the canal was placed into service. These bubbles caused the liner to balloon (commonly called "whales") and restrict canal flow. The irrigation district cut these liner "whales" in about a half-dozen locations during the 1993 irrigation season to relieve pressure, thereby allowing the liner to subside. Unlike the "whales" on test section 6 which contained trapped water, the district found that these "whales" contained gas and sand along with water. Large amounts of sand were found beneath some liner cuts during Reclamation's inspections, indicating transport of bedding material by water flowing beneath the liner, probably from one cut to the next. Large longitudinal wrinkles have formed in the liner, perhaps from the "whales" pulling the liner out from beneath the grout-filled mattress on the side slopes.

Also, a backhoe damaged the liner and the grout-filled mattress at the dike location between test sections 9 and 10 (station 65+00). Finally, dozens of small tears were found in the exposed VLDPE liner from the rocky subgrade. In addition to the liner damage, the grout mattress placement is quite irregular to accommodate the uneven side slopes.

To alleviate future problems with liner "whales," the liner will be anchored in the invert with concrete blocks or a concrete pad. A system to vent the gas bubbles is also being considered.

**Maintenance:** Extensive maintenance required to date

**Performed:** None

**Needed:** Repair cuts and tears in exposed VLDPE in invert. Repair grout-filled mattress at station 65+00 (downstream dike). Anchor geomembrane in invert with concrete. To perform repairs, irrigation district needs an extrusion welder, extra membrane, and specialized training.

**Photographs:** 33 through 38

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

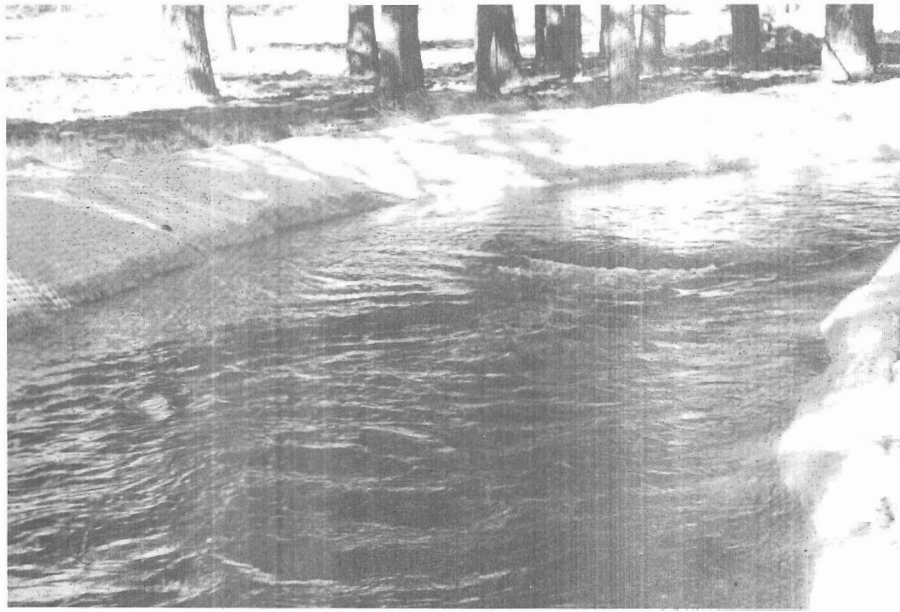


Photograph 33. - Canal overview—marginal condition.

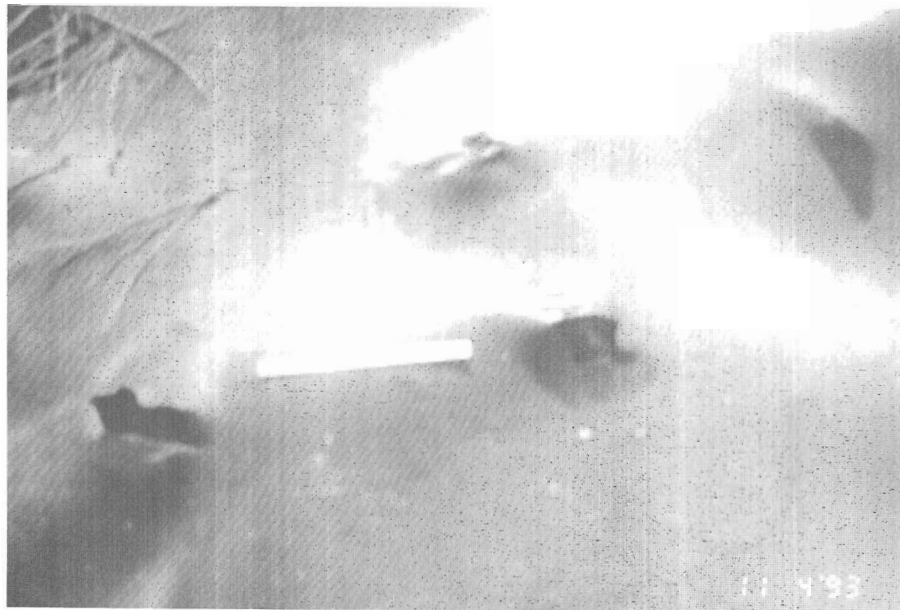


Photograph 34. - Extensive longitudinal wrinkles have developed in the canal invert.

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



Photograph 35. - Ballooned liner (whale) is just below the water surface, creating the "wave" in this photograph.

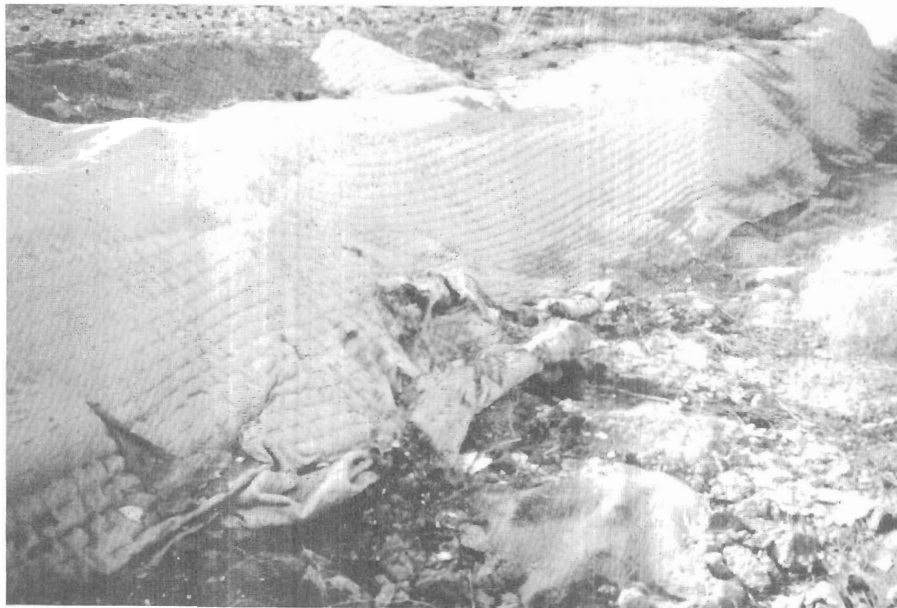


Photograph 36. - Tears over sharp rocks in invert.

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



Photograph 37. - Tear over large sharp subgrade rock.



Photograph 38. - Backhoe damage at downstream dike



### ***Test Section 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 (17 months old)

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

Condition: Marginal - lots of damage (mostly man-made). Gas bubbles (possibly volcanic in origin) developed in the invert under the liner when the canal was placed into service. These bubbles caused the liner to balloon (commonly called "whales") and restrict canal flow. The irrigation district cut these liner "whales" in about a half-dozen locations during the 1993 irrigation season to relieve pressure, thereby allowing the liner to subside. Unlike the "whales" on test section 6, which contained trapped water, the district found that these "whales" contained gas and sand along with water. Large amounts of sand were found beneath some liner cuts during Reclamation's inspections, indicating transport of bedding material by water flowing beneath the liner, probably from one cut to the next. Large longitudinal wrinkles have formed in the liner, perhaps from the "whales" elongating the geomembrane or pulling the liner out from beneath the grout-filled mattress on the side slopes.

Only a few rips were found in the exposed HDPE liner. Surprisingly, far more rips were found in the more flexible VLDPE on test section 9. We reviewed the construction records and found that the subgrade was more severe in test section 9, which accounts for the greater damage to the more flexible VLDPE.

We found occasional areas where the grout did not fill the mattress completely. We cut the grout mattress open at one location and found that dirt (not sand) had infiltrated into this void since the time of construction.

White "chalky" deposits were found in the invert throughout this test section, 1/2 to 4 inches thick, covering perhaps 50 percent of the invert. Visual examination and laboratory X-ray diffraction identified these deposits as pure hydrated portland cement with no aggregate (see appendix C for laboratory test results). "Lift lines" visible within the samples suggest that they were deposited in a sedimentary manner in standing or very slow moving water.

To confirm that the portland cement deposits came from the grout mattress, two samples of grout-filled mattress were taken to Denver and tested for cement content. One sample was taken from above the waterline in test section 8, and the second sample was taken below the waterline near the invert at the dike between test sections 9 and 10 (station 65+00 estimated). Laboratory test results are included in appendix D and show 28.5 percent cement ( $\approx$  8-sack mix) above the waterline in test section 8, and only 19.9 percent cement content ( $\approx$  6-sack mix) below the waterline in test sections 9 and 10. This difference suggests that a significant amount of cement may have washed out of the grout mattress below the waterline.

Two theories (neither totally satisfactory) have been developed to explain the presence of these portland cement deposits. The first theory is that this portland cement leached out of the grout mattress on test section 10 at the time of construction. Test sections 7, 9 and 10 were all reportedly constructed during wet rainy weather with standing water in portions of the invert; however, the geotextile mattress should have contained the cement grout even underwater. This theory also does not explain why all the deposits are on test section 10, but not in test sections 7 or 9.

The second theory is that this portland cement leached out of the grout mattress on test section 10 immediately after construction, as test section 10 was filled with water within 24 hours of cement grout placement. The other concrete canal linings all had three days or more to cure before being filled with water. Again, the geotextile grout mattress should have contained the cement grout, and this theory does not explain why the portland cement deposited in test section 10 rather than washing away downstream.

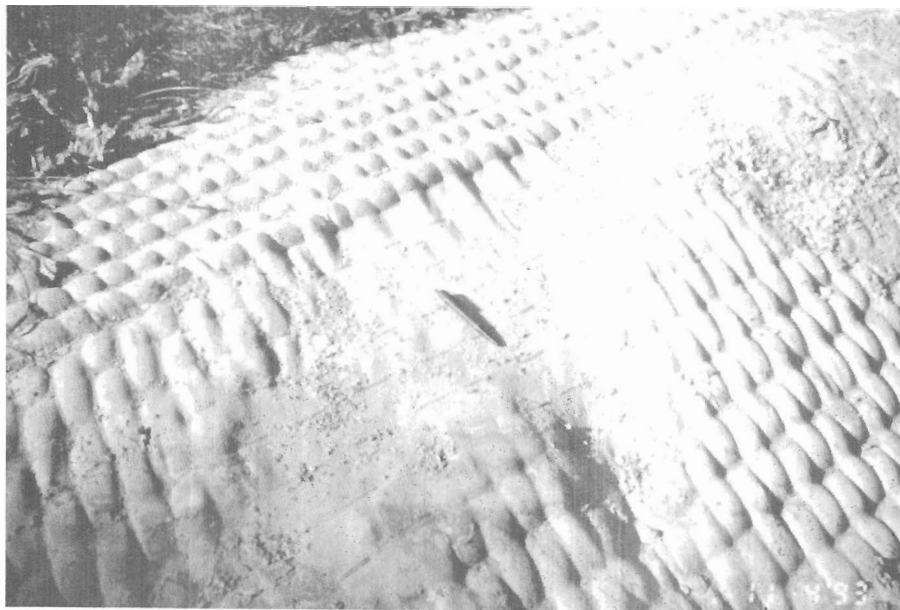
Small chunks of portland cement were observed in the canal immediately downstream from test section 10. These fragmented pieces were originally deposited in test section 10 and later washed downstream.

Maintenance:	Extensive maintenance required to date
Performed:	Removed about half of the portland cement deposits (cost = \$320)
Needed:	Remove remaining portland cement deposits. Repair cuts and tears in exposed HDPE in invert. Anchor geomembrane in invert with concrete blocks or a concrete pad. Patch grout mattress where not full of grout. To perform repairs, irrigation district needs an extrusion welder, extra membrane, and specialized training.
Photographs:	39 through 44

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



Photograph 39. - Canal overview—marginal condition.



Photograph 40. - Empty pocket in grout mattress.

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

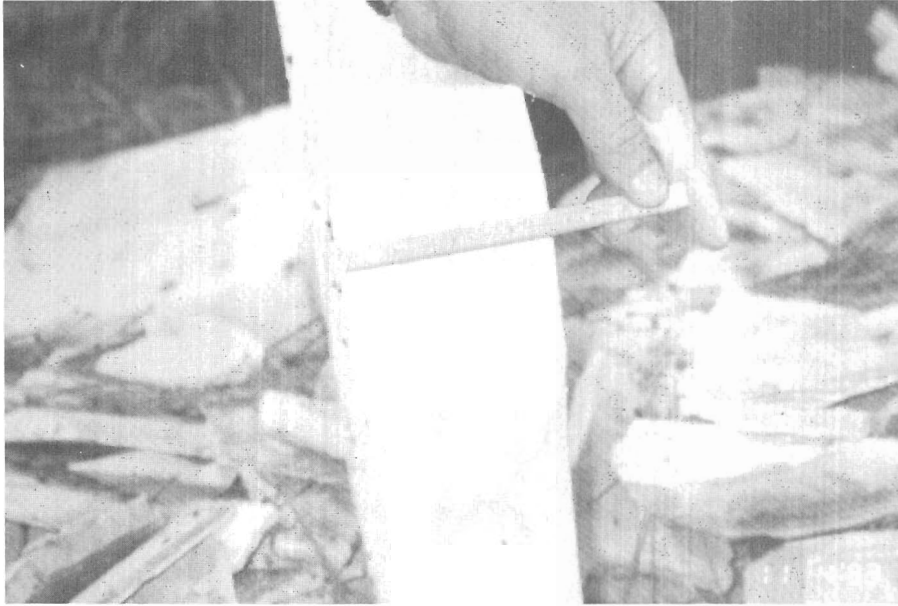


Photograph 41. - White "chalky" portland cement deposits in invert.



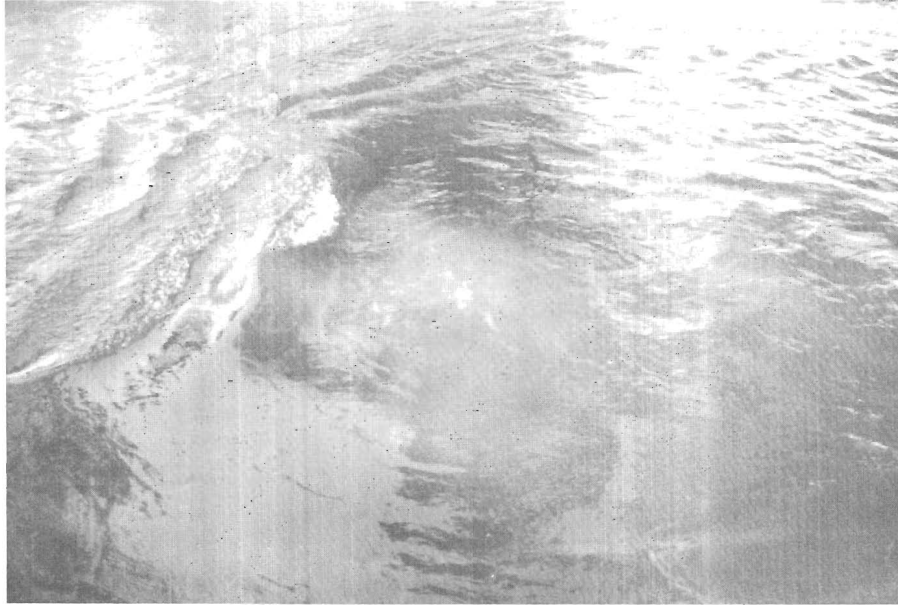
Photograph 42a. - Irrigation district removed some of the portland cement deposits in October 1993.

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

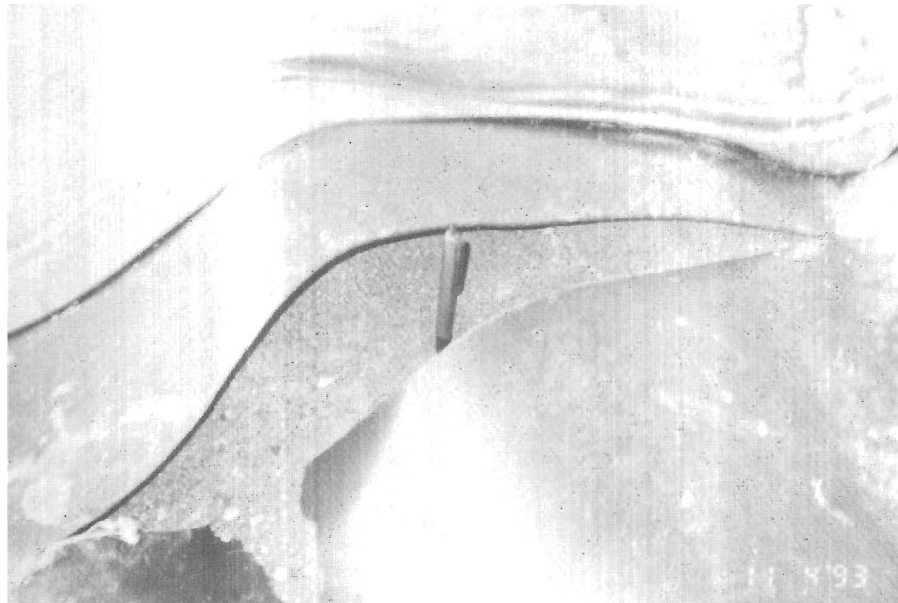


Photograph 42b. - Portland cement deposits are up to 4 inches thick.

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



Photograph 43. - Ballooned liner (whale) is just below the surface, causing the wave shown in this photograph.



Photograph 44. - Cut in geomembrane to relieve "whale". Sand deposits found beneath liner.

## North Unit Main Canal

### *Test Section 1.—*

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

**Description:** SPF is 2 inches of 2-pound (lb/ft<sup>3</sup>) 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 (13 months old)

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

**Condition:** Partially failed - large section of foam (about 1,000 square feet) has washed out in the invert just below the drop at station -1+00 (estimated). This washout occurred in the first few weeks of service (summer 1993). The washed-out foam was found 16 miles downstream at a siphon inlet. The foam failure initiated in loose sand and gravel deposits that offered no uplift resistance to the buoyant foam. The high velocity water then undercut large, loose subgrade rocks, allowing more foam to break free. Some of the washed-out foam remained bonded to large rocks (6- to 12-in diameter). The foam apparently provided sufficient buoyancy to float the rocks downstream. One cubic foot of 2-pound foam provides enough buoyancy to float a 100-pound rock.

In addition to the washed-out foam, about 2,000 square feet of the remaining foam lost its protective coating. Poor bond between the tan basecoat and the foam was anticipated because the foam was installed in October 1992, and the protective coating was not applied until March 1993. Bond appears good between the tan basecoat and white topcoat. Also, in a couple of small areas (less than 100 square feet), the 5-pound top-foam has delaminated from the 2-pound base-foam. Above the waterline, the foam and coatings are intact.

**Maintenance:** Extensive maintenance required to date

**Performed:** Irrigation district removed washed-out foam from siphon inlet (cost = \$ 1387). Installed weed rack at siphon (cost = \$ 240). Total cost = \$ 1627.

**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:** 45 through 50

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



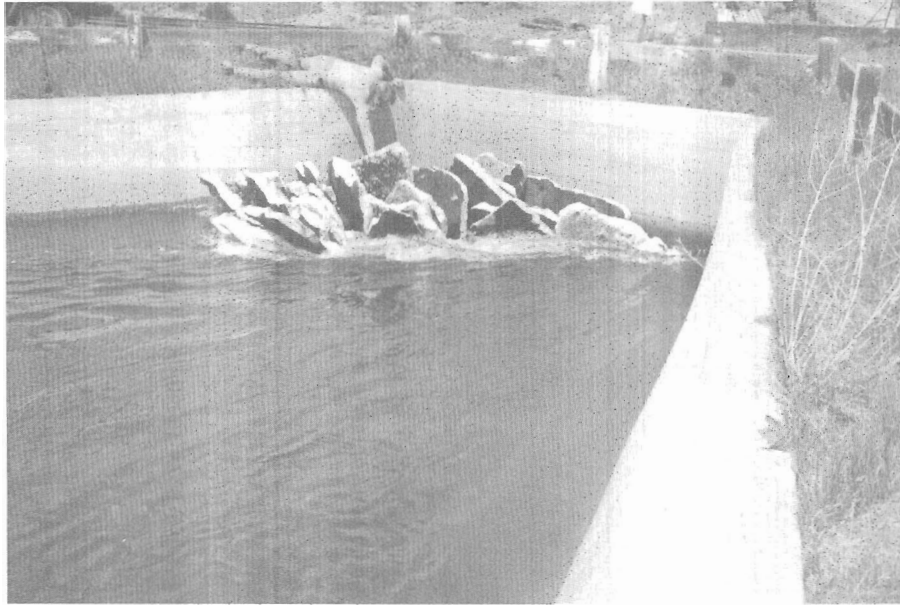
Photograph 45. - Canal overview—foam in the invert has washed out near the bridge.



Photograph 46. - Drop section just upstream from bridge (photo taken from bridge).



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

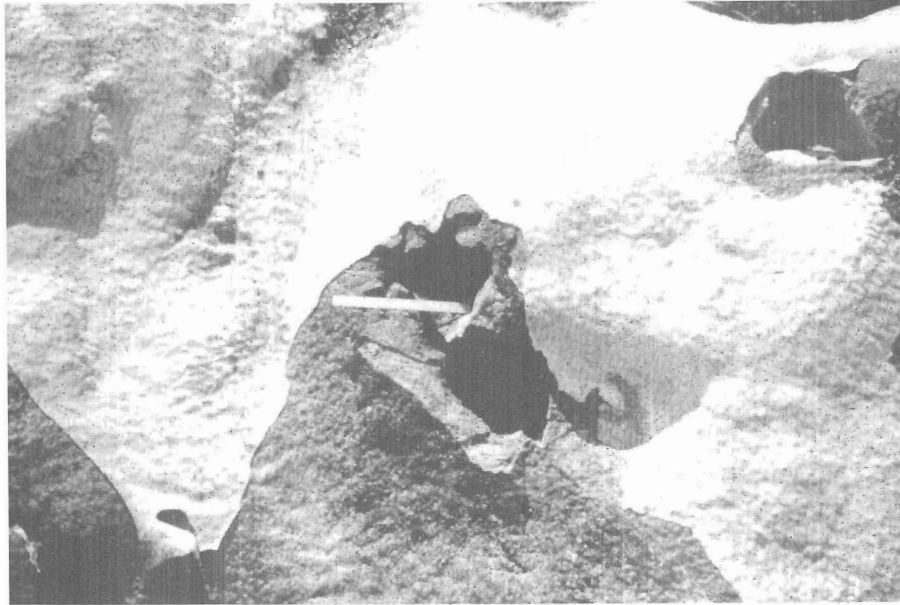


Photograph 47. - Washed-out foam collected downstream at siphon inlet.

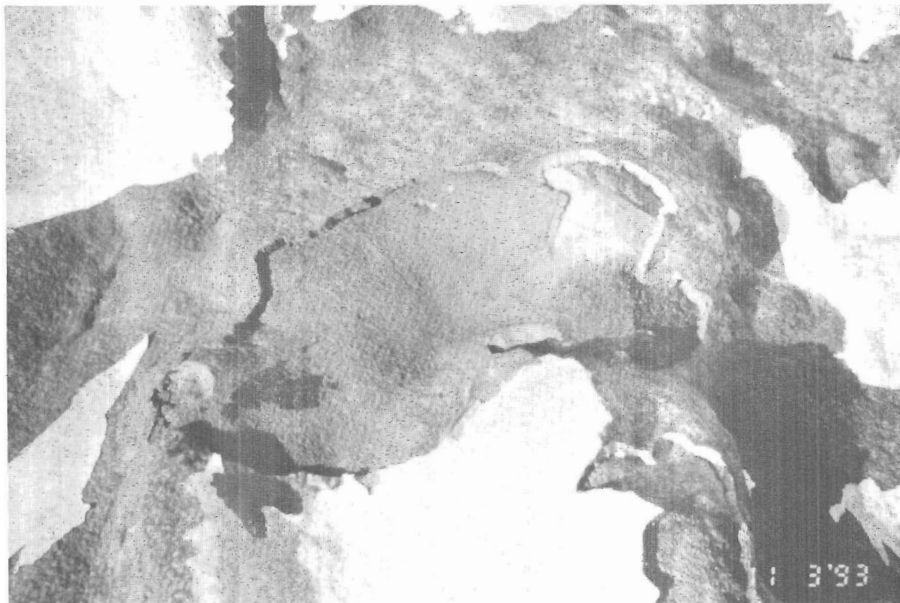


Photograph 48. - Foam is well-bonded to subgrade rocks and provided sufficient buoyancy to "float" even large rocks (6- to 12-inch diameter).

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



Photograph 49. - Poorly bonded coating stripped from foam.



Photograph 50. - Small amount of 5-pound foam has disbonded from underlying 2-pound foam.

## ***Test Section 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 (19 months old)

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

**Condition:** Partially failed - large section of foam (about 1,000 ft<sup>2</sup>) has washed out in the invert on the upstream end adjoining test section 1. This washout occurred in the first few weeks of service (summer 93). The foam washout apparently initiated in an area of loose sand and gravel in test section 1. High velocity water allowed foam failure to propagate downstream into test section 2, stopping where foam is bonded to a solid concrete slab. Only a small amount (≈1%) of the remaining foam lost its Geothane 5020 coating - perhaps because of lower velocities in this test section, or because the foam and coating were both installed at same time. In some areas, the coating could easily be peeled from the foam, indicating weak bond. Several areas also show weak bond within the Geothane 5020. Because 5020 was applied in a single coat, it might have been applied too thick, or perhaps the contractor waited too long between passes when building up the coating thickness. Above the waterline, the foam and coating are intact.

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). The foam apparently provided sufficient buoyancy to float the rocks downstream. One cubic foot of 2-pound foam provides enough buoyancy to float a 100 pound rock.

**Maintenance:** Extensive maintenance required to date

**Performed:** Irrigation district removed washed-out foam from siphon inlet (cost = \$ 1387). Installed weed rack at siphon (cost = \$ 240). Total cost = \$ 1627.

**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:** 51 through 54

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



Photograph 51. - Canal overview—partially failed. Foam has washed out under bridge in upstream half of this test section.



Photograph 52. - Small areas where coating is not well bonded to the foam.

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



Photograph 53. - Irrigation district removes washed-out foam where it collected at siphon inlet.



Photograph 54. - Several cubic yards of washed-out foam were collected at the siphon inlet.

### ***Test Sections 3 and 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 (19 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 (spring 1993). The geotextiles tore at the foam anchor trench, and several large sections of geotextile washed downstream, damaging a pipeline crossing. The irrigation district removed all remaining liner in these two test sections.

**Maintenance:** Extensive repairs required to date

**Performed:** Fall 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- by 3-foot concrete cap. The cost was \$555 for each test section.

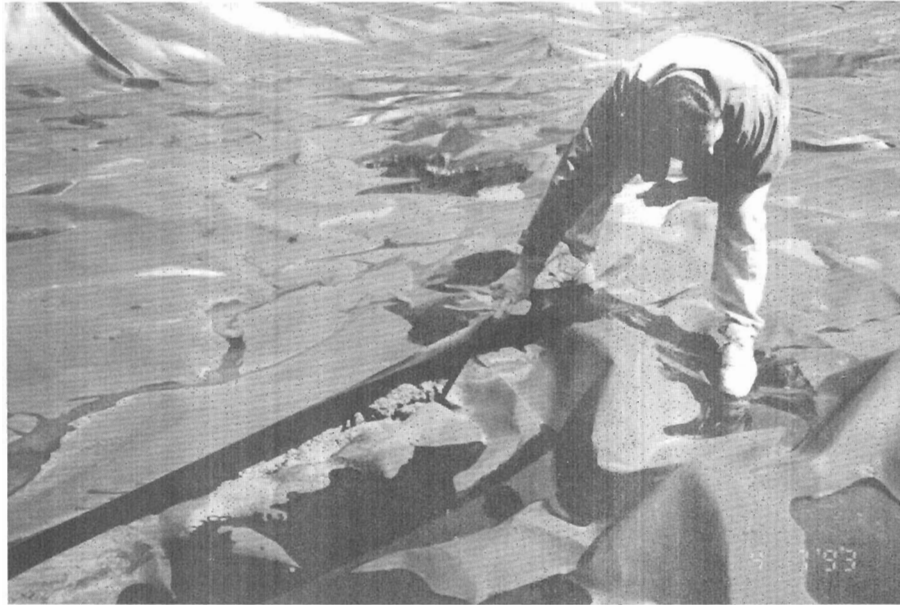
Spring 1994 - Irrigation district removed all remaining geotextile liners (cost = \$ 1387 each), and repaired the COI pipeline crossing (cost = \$ 803 per test section)

Total maintenance costs = \$ 2745 each test section

**Needed:** None - both linings have been removed.

**Photographs:** 55 through 64

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

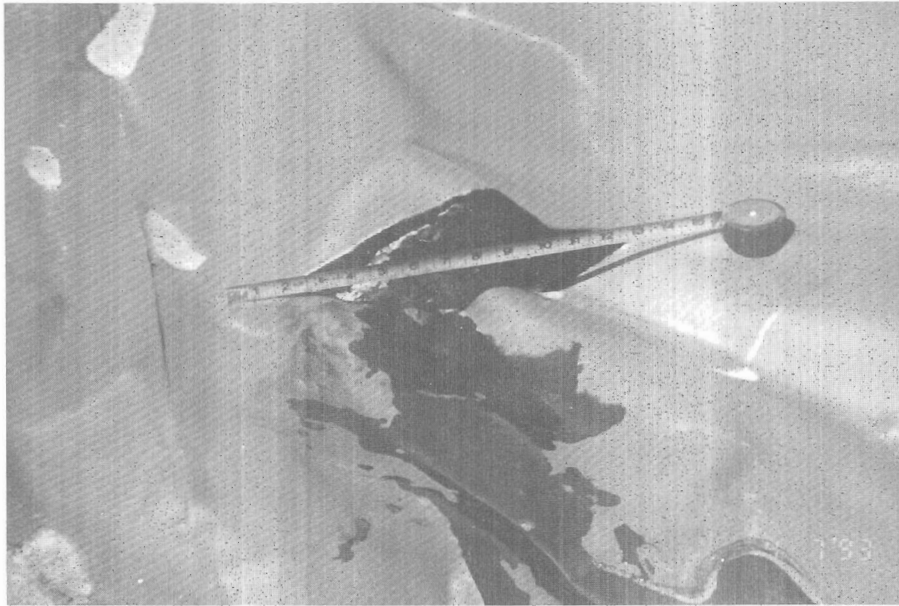


Photograph 55. - 20-foot seam with essentially zero bond.

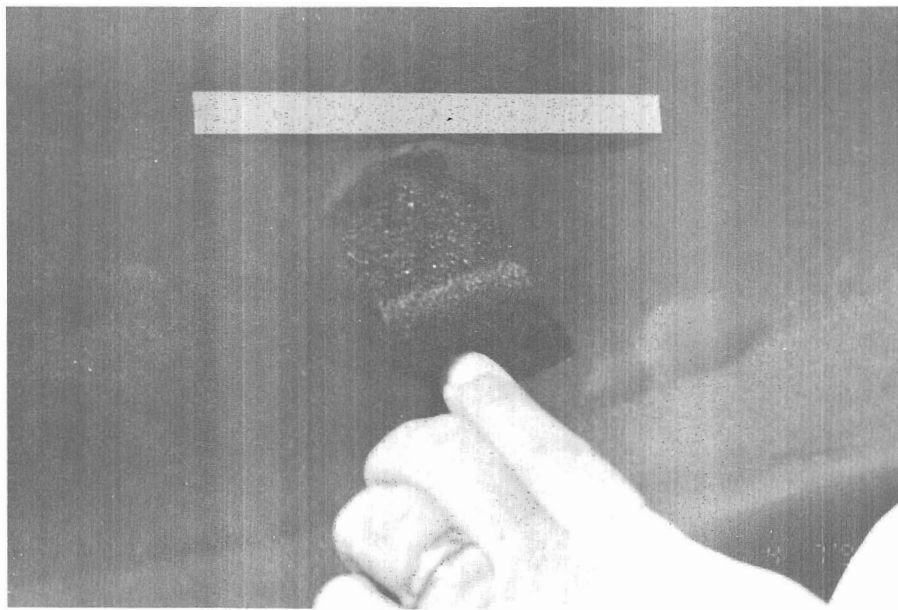


Photograph 56. - Irrigation district repairs seam with a concrete cap.

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



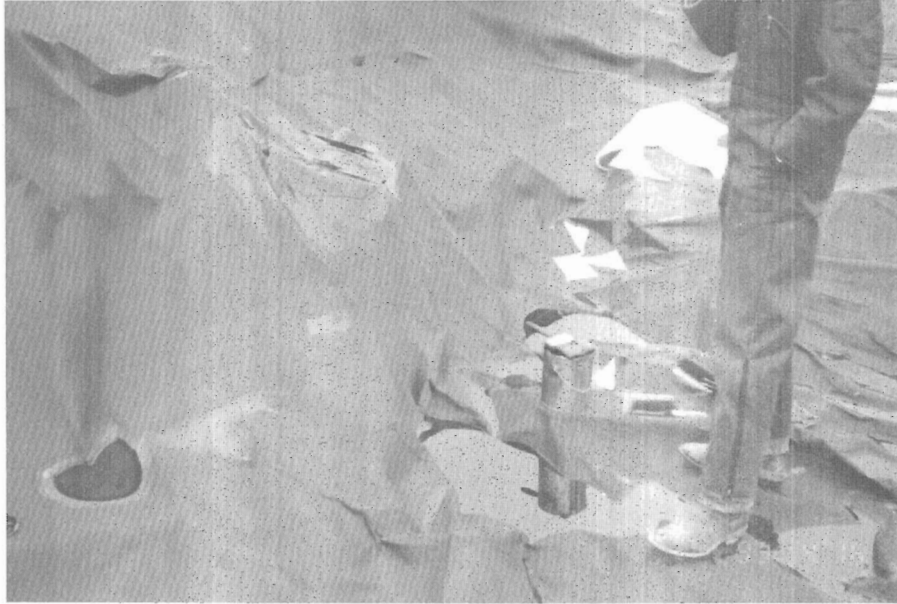
Photograph 57. - Dozens of rips in geotextile around rocks.



Photograph 58. - Blister in Geothane 5020 coating, applied too thick?



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



Photograph 59. - Irrigation district used hand-mix version of Geothane 5020 for repairs.



Photograph 60. - Completed geotextile patch.

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



Photograph 61. - Sections of geotextile liner tore loose when the canal was filled with water.



Photograph 62. - Runaway floating geotextile liner damaged the pipe crossing shown near bridge.

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



Photograph 63. - Geotextile liner tore parallel to foam anchor trench.



Photograph 64. - Irrigation district removed all remaining geotextile liner from these test sections.

**Test Sections 6-9.**—These general comments apply to all four shotcrete test sections:

Material: 3-inch shotcrete

Date Installed: February 1992 (26 months old)

Condition: Excellent - all the shotcrete looks to be in excellent condition. No visible differences exist in the four shotcrete test sections. No freeze-thaw damage is evident. Ponded water near a drop structure, being used as a swimming hole by local wildlife, indicates a low seepage rate. Small ponds are present on all four test sections.

Contraction cracks on the sidewalls have developed every 100 to 200 feet. Crack width varies from hairline to 1/8 inch. Cracks do not extend completely across the canal prism, but instead usually disappear somewhere in the invert. These cracks will be monitored for growth. Also, some small irregular voids (holes) were found in the shotcrete, ranging in depth up to 4 inches (see photo 67).

The thickness of the shotcrete is in question 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). If 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 exposed aggregate in the invert caused by erosion of the surface cement. These areas will be monitored to assess the severity of abrasion.

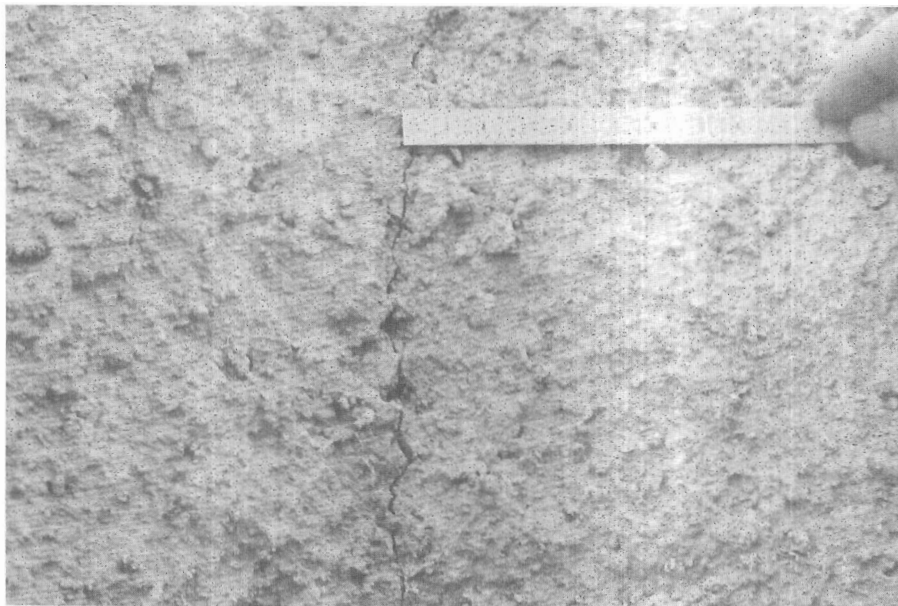
Many large rocks (typically 12 inches in diameter) are collecting in the canal invert (probably rolled in by local residents). Weeds are growing out of cracks in the shotcrete near the top of side slopes.

Photographs: 65 through 68

**North Unit Canal - Test Sections 6, 7, 8 & 9**  
**3-inch Shotcrete**



Photograph 65. - Canal overview—excellent condition. Boulders in invert were probably rolled in by local residents.



Photograph 66. - Transverse contraction cracks in side slopes every 100 to 200 feet.

**North Unit Canal - Test Sections 6, 7, 8 & 9**  
**3-inch Shotcrete**



Photograph 67. - Vegetation occasionally growing out of shotcrete on side slopes.



Photograph 68. - Occasional holes in shotcrete up to 4 inches deep.

### ***Test Section 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<sup>3</sup>  
\$1.44 at a fiber dosage of 25 lb/yd<sup>3</sup>

**Date Installed:** February 1992 (26 months old)

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

**Condition:** Excellent - shotcrete performing well. On the left side (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. One 2-foot-diameter hole developed in the shotcrete on the side slope, and a second 2-foot-diameter hole developed in the invert. 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<sup>3</sup>.

**Maintenance:** Minimal maintenance required to date

**Performed:** The first year, the irrigation district repaired a hole in the shotcrete lining and removed some large rocks (cost = \$ 835). The irrigation district patched another hole in the shotcrete the next year (cost = \$ 142). Total cost = \$ 977.

**Needed:** None—no specialized equipment or training required

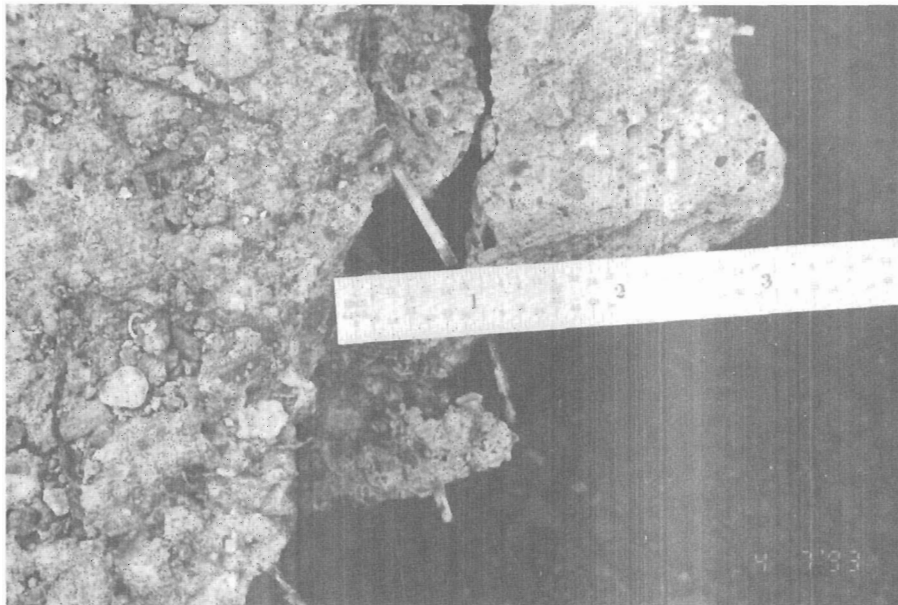
**Photographs:** 65 through 68 and  
69 through 71



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



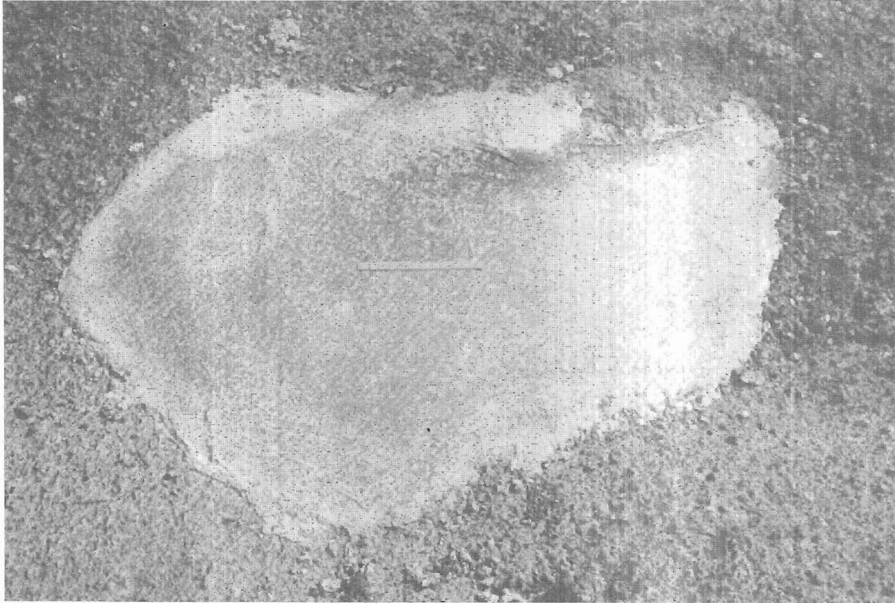
Photograph 69. - Two-foot-diameter hole in shotcrete on left bank.  
Shotcrete is only about 1 inch thick at this location.



Photograph 70. - Exposed steel fibers have corroded and are quite weak.  
Embedded steel fibers have been protected and are still shiny.



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



Photograph 71. - Irrigation district patched two 2-foot-diameter holes that developed in the shotcrete.

***Test Section 7.—***

Material: 3-inch shotcrete reinforced with Phillips polyfibers

Description: Polyfibers are 3/4-inch Phillips Fi-con polypropylene fibers

Construction Cost: \$1.39 per square foot at fiber dosage of 1½ lb/yd<sup>3</sup>  
\$1.47 per square foot at fiber dosage of 3 lb/yd<sup>3</sup>

Date Installed: February 1992 (26 months old)

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

Condition: Excellent - shotcrete performing well. Polyfibers are visible on the shotcrete surface. No visible differences were noted between the first 250-foot section containing 3 pound of polyfibers per cubic yard of shotcrete and the second 250-foot section with 1.5 lb/yd<sup>3</sup>.

Maintenance: No maintenance required to date

Performed: None

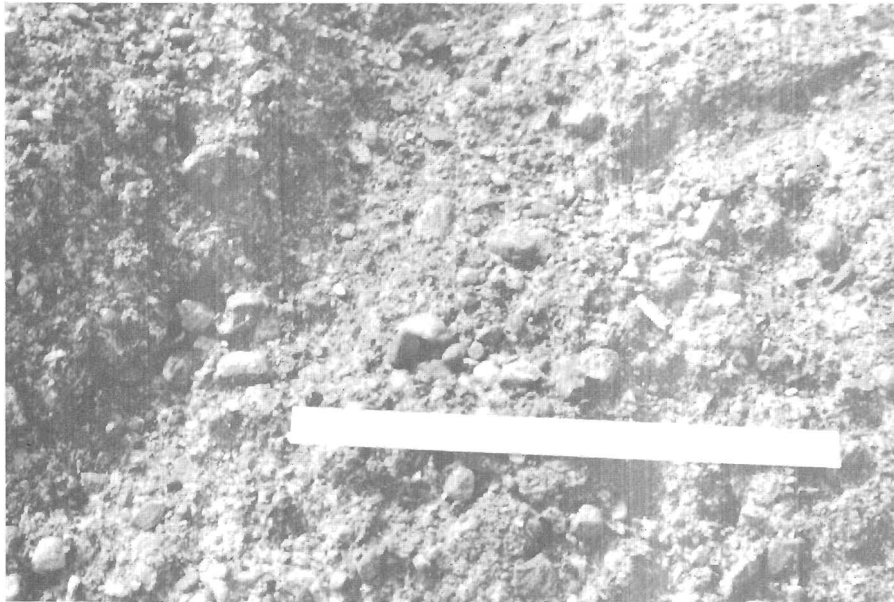
Needed: None—no specialized equipment or training required

Photographs: 65 through 68 and 72 through 75

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

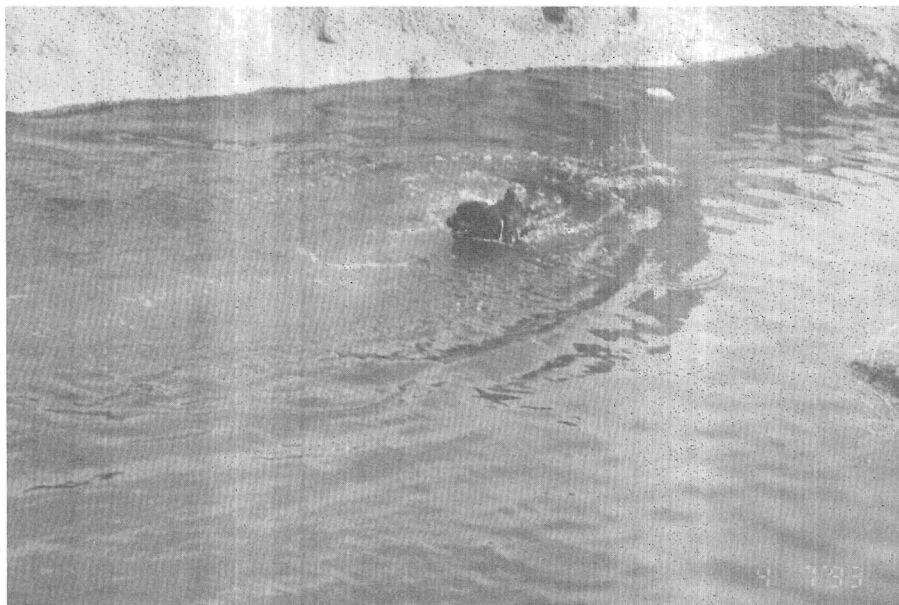


Photograph 72. - Drop section with smaller cross-section and higher velocities.



Photograph 73. - High velocity water has eroded surface cement, exposing aggregate.

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



Photograph 74. - Pond immediately upstream from drop structure has become a favorite swimming hole for local wildlife.



Photograph 75. - Rough shotcrete surface allows for animal escape.

***Test Section 8.—***

Material: 3-inch shotcrete reinforced with Fibermesh polyfibers

Description: Polyfibers are Fibermesh Harbourite 320 (¾-inch-long fibrillated polypropylene fibers).

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

Date Installed: February 1992 (26 months old)

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

Condition: Excellent - shotcrete performing well. 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<sup>3</sup>.

Maintenance: No maintenance required to date

Performed: None

Needed: None—no specialized equipment or training required

Photographs: 65 through 68

***Test Section 9.—***

Material: 3-inch unreinforced shotcrete

Construction Cost: \$1.33 per square foot

Date Installed: February 1992 (26 months old)

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

Condition: Excellent - shotcrete performing well.

Maintenance: No maintenance required to date

Performed: None

Needed: None—no specialized equipment or training required

Photographs: 65 through 68

## **FUTURE STUDIES**

1. Additional test sections - two additional test sections were constructed in 1994. A supplemental "Construction Report" will be published to document the construction of these test sections. The techniques include:
  - Liquid Boot - Tumalo Irrigation District used their own forces (under the supervision of a Liquid Boot applicator) to spray-apply Liquid Boot to the inside of one metal flume. Liquid Boot was also used to line a portion of a concrete flume.
  - Siplast - Lugert Altus Irrigation District used their own forces to install about 20,000 square feet of Siplast to their canal in Altus, Oklahoma.
2. Seepage studies - post-construction ponding tests are scheduled for the four shotcrete linings on the North Unit Canal. The North Unit Irrigation District will perform these ponding tests in the fall of 1994.

To determine long-term seepage rates, additional post-construction ponding tests on both the Arnold and North Unit test sections are planned for 1997 (year 5) and 2002 (year 10).
3. Durability reports - additional durability reports will be published every 2 to 3 years to document visual inspections, lining performance, and maintenance costs.
4. Final report - the final report is scheduled for publication in 2002 (year 10), and will provide long-term data on the design life, maintenance costs, life-cycle costs, long-term seepage rates, and the cost of conserved water for each test section.





**Appendix A**  
**Maintenance Data Sheets**  
**Arnold Canal**



Form Number 2  
Record of Irrigation District Contributed Goods and Services  
for Annual Operation, Maintenance, and Replacement  
Canal Lining Demonstration Project  
Arnold Irrigation District

Report for Calendar Year 1993

Test Section Number: 10      Supplier: Arnold Irrigation Dist

Briefly describe any required operation, maintenance, or replacement actions needed for this canal test section this past year:

1. Remove Cement Deposits (Oct 93)

**LABOR:** List by task the type of labor employed and the number of hours worked. For example: Repairing Rock Damage; Common Labor; 5 hours.

1. Remove Cement Deposits: 12 hrs Common Labor (3 men/4 hrs)  
12 hrs @ \$10 = \$120

**MATERIALS.** List by task the type and quantity of materials supplied. For Example: Repairing Rock Damage; Bituminous Patching Compound: 5 pounds.

1. None

**EQUIPMENT.** List by task the type and quantity of equipment used. For instance: Repairing Rock Damage; Butane Torch; 3 hours.

1. Backhoe      4 hrs @ \$50 = \$200

Table 4 - Maintenance Cost - Arnold Canal

#	Test Section	Maintenance	Cost (\$)	Total Cost (\$)
1	Petromat with 3 inch Shotcrete Cover	None		
2	30 mil VLDPE with 3 inch Shotcrete Cover	None		
3	Exposed 80 mil HDPE	None		
4	Exposed Geolam	None		
5	Exposed 45-mil Hypalon	None		
6	Exposed 36-mil Terra Tuff	None		
7	40-mil PVC with 3 inch Grout-filled Mattress	None		
8	3-inch Grout filled Mattress	None		
9	Exposed VLDPE with Grout-filled Mattress on sideslopes only	None		
10	Exposed HDPE with Grout filled Mattress on Side slopes only	Clean Lining Backhoe	\$ 120 \$ 200	\$ 320

**Appendix B**  
**Maintenance Data Sheets**  
**North Unit Main Canal**



## STATEMENT

## NORTH UNIT IRRIGATION DISTRICT

2024 N.W. Beech Street • Madras, Oregon 97741 • (503) 475-3625  
DESCHUTES PROJECT

June 1993

Bureau of Reclamation  
1150 N. Curtis Road  
Boise, ID 83706

PLEASE DETACH AND RETURN THIS PORTION OF STATEMENT WITH YOUR REMITTANCE \$ \_\_\_\_\_

Est Section	DATE	CHARGES	CREDITS	BALANCE	Totals
1 and 2 3 and 4		Canal Lining Demonstration Project Removing Foam & Lining 5-14-93 to 6-3-93 Labor - 7 Employees/204 hours Backhoe - 40 hours @ 45.00 10 Yd. Dump Truck - 16 hours @ 25.00		2,843.14 1,800.00 400.00	\$547 total \$1387 each
1 and 2		Installing Weed Rack 5-15-93 Labor - 4 Employees/31½ hours		435.57	\$480 total \$240 each
3 and 4		Repairing C.O.I. Delivery 5-6-93 Labor - 6 Employees/33½ hours Backhoe - 6½ hours @ 45.00 Materials - Premix, Pipe & Supplies		561.93 292.50 605.69	\$1600 total \$803 each
		Administrative Overhead 10%		6,938.83 693.88 7,632.71	\$7633

PLEASE PAY LAST AMOUNT  
IN THIS COLUMN

7

Form Number 2  
Record of Irrigation District Contributed Goods and Services  
for Annual Operation, Maintenance, and Replacement  
Canal Lining Demonstration Project  
North Unit Irrigation District

Report for Calendar Year: April 93

Test Section Number: 344 Supplier: North Unit Irrigation District

Briefly describe any required operation, maintenance, or replacement actions needed for this canal test section this past year:

Patching lining

LABOR. List by task the type of labor employed and the number of hours worked. For example: Repairing Rock Damage; Common Labor; 5 hours.

Patching lining; common labor; 56 hours	28 @ 16.37	458
	28 @ 16.76	469

MATERIALS. List by task the type and quantity of materials supplied. For example: Repairing Rock Damage; Bituminous Patching Compound; 5 pounds.

Patching lining; Fiberglass mat	3	21.28	21
Brushes	10	22.30	22
Sandpaper	5	3.74	4
Premix concrete	13 sacks	43.37	43
Duct tape	1 roll	4.49	4
Fiberglass cloth	1	19.15	19

EQUIPMENT. List by task the type and quantity of equipment used.  
instance: Repairing Rock Damage; Butane Torch; 3 hours.

*Geothume 520*

70  

---

#1110



7

Form Number 2  
Record of Irrigation District Contributed Goods and Services  
for Annual Operation, Maintenance, and Replacement  
Canal Lining Demonstration Project  
North Unit Irrigation District

Report for Calendar Year: 92

Test Section Number: 8 Supplier: North Unit Irrigation District

Briefly describe any required operation, maintenance, or replacement actions needed for this canal test section this past year:

Patch one hole in lining  
Removed large rock

LABOR. List by task the type of labor employed and the number of hours worked. For example: Repairing Rock Damage; Common Labor; 5 hours.

Repairing rock damage: common labor	8 hours	4 @ \$16.37	65
		4 @ \$15.76	63
Removing large rock: common labor	36 hours	12 @ \$16.36	196
		12 @ \$10.67	128
		12 @ \$15.76	189

MATERIALS. List by task the type and quantity of materials supplied. For example: Repairing Rock Damage; Bituminous Patching Compound; 5 pounds.

Repairing rock damage: patching	4 sacks premix concrete	
		4 @ \$3.49 14

EQUIPMENT. List by task the type and quantity of equipment used. For instance: Repairing Rock Damage; Butane Torch; 3 hours.

Removing large rock: boom truck	12 hours	@ \$15 <sup>00</sup>	180
			<u>\$835</u>

7

Form Number 2  
Record of Irrigation District Contributed Goods and Services  
for Annual Operation, Maintenance, and Replacement  
Canal Lining Demonstration Project  
North Unit Irrigation District

Report for Calendar Year: 93 April

Test Section Number: 8 Supplier: North Unit Irrigation District

Briefly describe any required operation, maintenance, or replacement actions needed for this canal test section this past year:

Patch one hole in lining

LABOR. List by task the type of labor employed and the number of hours worked. For example: Repairing Rock Damage; Common Labor; 5 hours.

Repairing rock damage: common labor	8 hours	4 @ \$16.37	65
		4 @ \$15.76	63

MATERIALS. List by task the type and quantity of materials supplied. For example: Repairing Rock Damage; Bituminous Patching Compound; 5 pounds.

Repairing rock damage: patching	4 sacks premix concrete
---------------------------------	-------------------------

4 @ \$3.49 14

EQUIPMENT. List by task the type and quantity of equipment used. For instance: Repairing Rock Damage; Butane Torch; 3 hours.

\$142

**Appendix C**  
**Laboratory Test Results**  
**X-ray Diffraction**

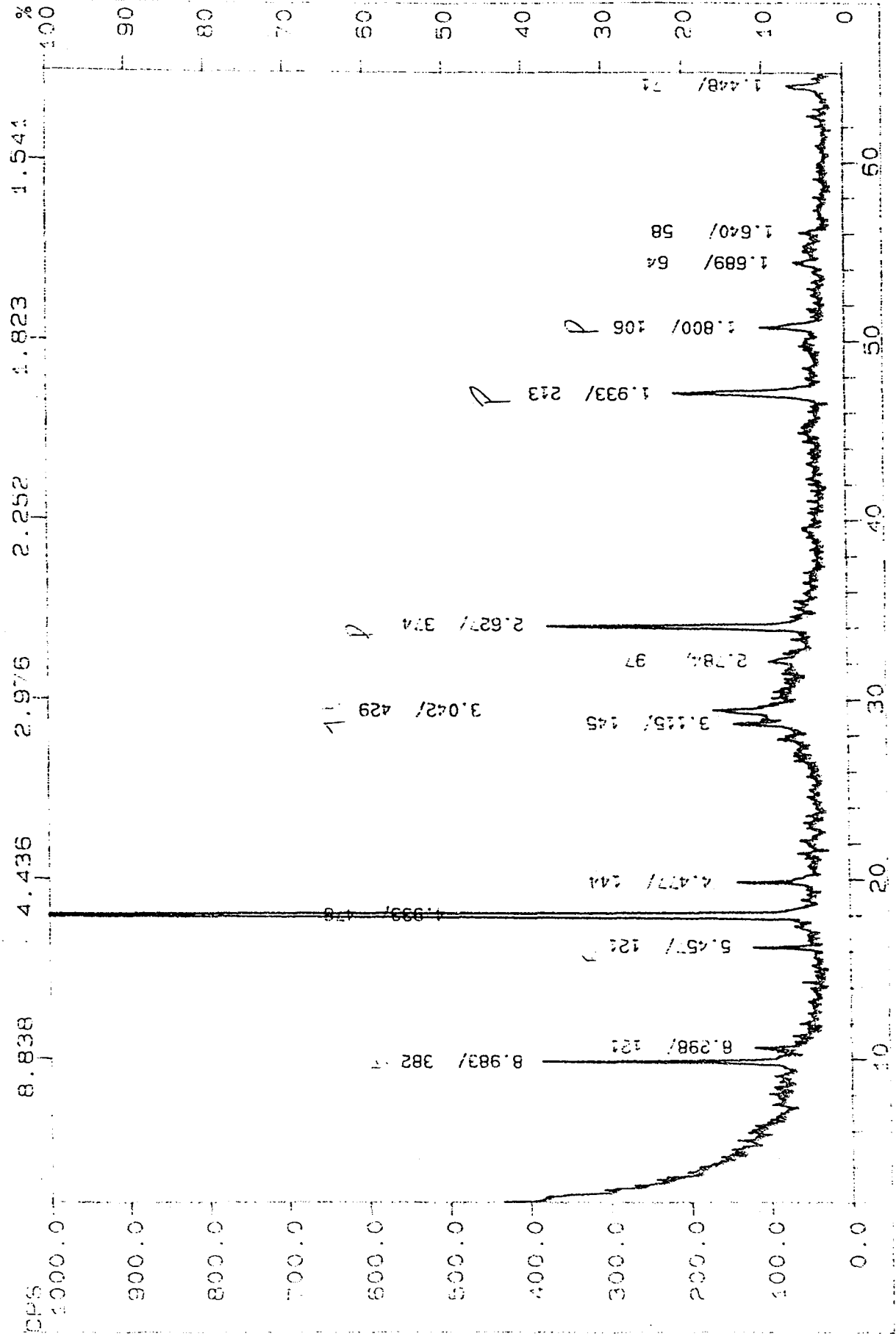


## DENVER OFFICE PETROGRAPHIC LABORATORY

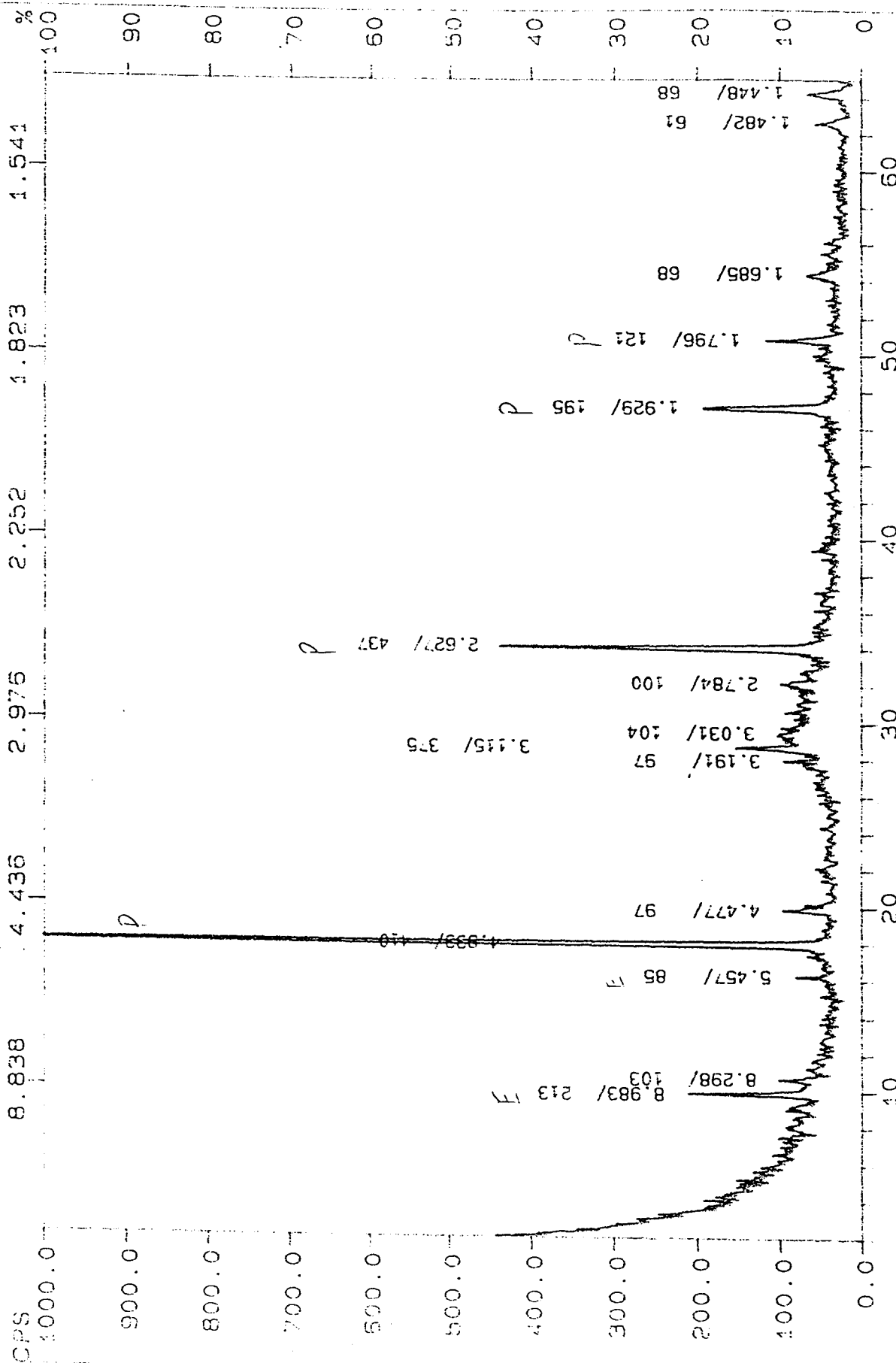
Several chunks of a white chalky deposit from the Deschutes Canal Lining were submitted to the Petrographic Laboratory in early November 1993. The samples were visually identified as pure hydrated portland cement with no aggregate. "Lift lines" visible within the samples suggest that they were deposited in a sedimentary manner in standing or very slow moving water.

To confirm that the samples are hydrated portland cement, four physically distinct portions of the samples were analyzed using X-ray diffraction technique. All were found to contain major amounts of portlandite  $[\text{Ca}(\text{OH})_2]$  and ettringite  $[\text{Ca}_6\text{Al}_2(\text{SO}_4)_3(\text{OH})_{12} \cdot 26\text{H}_2\text{O}]$ , both of which are portland cement hydration products.

FN: 93-35A.RD  
 DATE: 11/12/93  
 ID: DESCHUTES CANAL LINING WHITE  
 TIME: 13:29  
 PT: 0.450  
 STEP: 0.0300  
 WL: 1.54060  
 SCINTAG/USA



FN: 93-35B.RD ID: DESCH. CANAL LIN. GRY + WHITE SCINTAG/USA  
 DATE: 11/12/93 TIME: 15: 45 PT: 0.450 STEP: 0.0300 WL: 1.54060

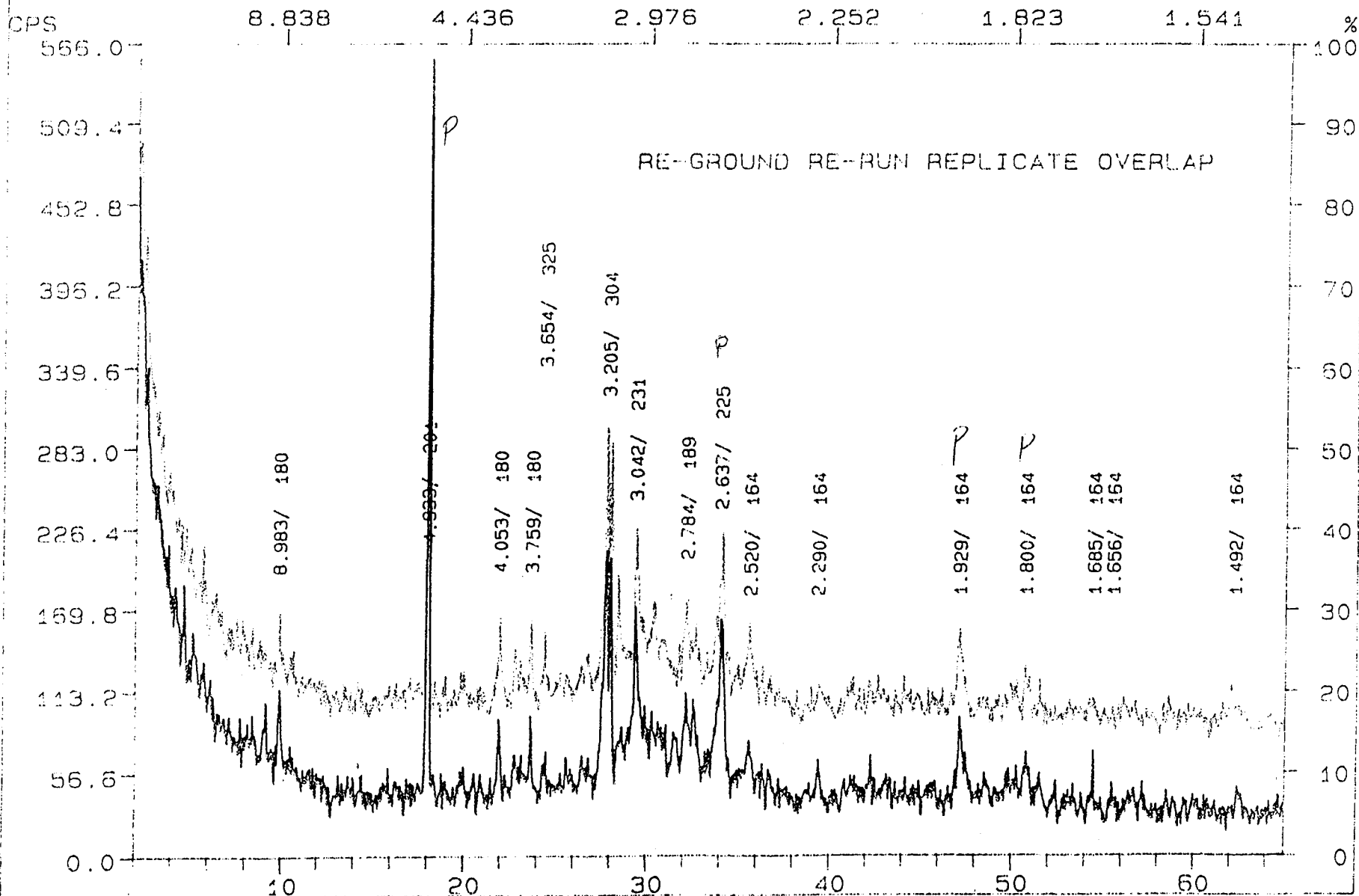


FN: 93-35C.RD  
DATE: 11/12/93

ID: DESCH. CANAL LINING, BLADED  
TIME: 14: 21

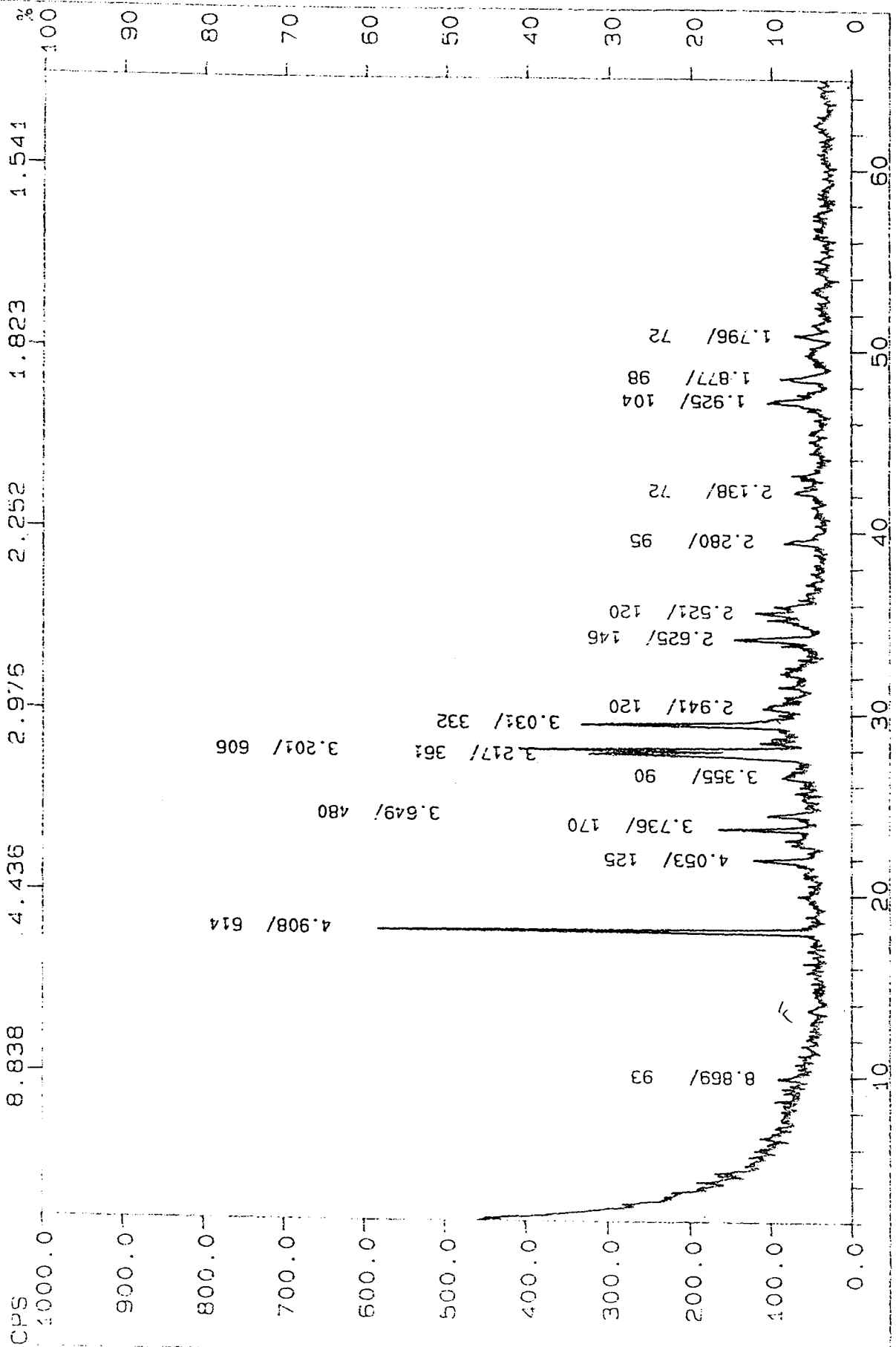
PT: 0.450  
STEP: 0.0300

SCINTAG/USA  
WL: 1.54060





FN: 93-35D.RD ID: DESCH. CANAL LINING. COARSE SCINTAG/USA  
 DATE: 11/12/93 TIME: 15:00 PT: 0.450 STEP: 0.0300 WL: 1.54050





**Appendix D**  
**Laboratory Test Results**  
**Cement Content**



D-3743A  
RES-3.20

FEB 03 1994

MEMORANDUM

To: Head, Corrosion and Plastics Technology Team  
Attention: D-3732 (Swihart)

From: Margaret Lake  
Acting Supervisor, Chemistry and Petrography Laboratory

Subject: Report of Chemical Analyses for Percent Cement in Concrete -  
Deschutes Samples

Attached are chemical analyses data for percent cement in concrete for samples submitted to our laboratory on December 17, 1994. The samples were received in good condition. Preliminary data were E-mailed to you on January 31, 1994.

Sample #1 - below waterline - 19.9 percent cement  
Sample #2 - above waterline - 28.5 percent cement

American Society of Testing Materials Method C-85 was followed. The Ca content was determined by Inductively Coupled Argon Plasma.

All data meet laboratory quality standards. Holding times were met for all samples.

Please advise us if you have any problems with our performance on blind QA samples you may have submitted.

If you have any questions regarding this report, please contact your project representative, Margaret Lake, 236-5260, 8D037001:MLAKE, or our QC Officer, Doug Craft, 303-236-4294, 8D037001:DCRAFT. We appreciate the opportunity to provide quality chemical analyses and service for your project.

*Margaret A Lake*

Attachment

cc: D-3732, D-3743A (Files), D-3743A (Klein)  
(w/attachment to each)

WBR:MLake:cs:2/1/94:236-5260  
(deschute.ml)

\*\*\*\*\*  
SAMPLE LOG-IN SUMMARY  
USBR CHEMISTRY LABORATORY  
DENVER, COLORADO  
\*\*\*\*\*

BATCH NUMBER..... 81  
DATA disk file name....PN4579

=====

Type of samples.....miscellaneous  
Submitted by.....D-3732 (Swihart)  
Number of samples.....2  
Chem lab numbers.....H- 4579 to 4580  
Sampling date.....12/17/1993  
Requested analyses.....cement content (C-1084)  
Region of origin.....PN  
Project.....Deschutes  
Feature.....cement

=====

Recall number.....WS029  
DUE DATE.....02/01/1994  
PRIORITY.....Medium

=====

SAMPLE IDENTIFIERS

SAMPLE 1 H-4579 #1 - below waterline  
SAMPLE 2 H-4580 #2 - above waterline

=====

#	Sample Name	CAmg/L
1	KSRT109	34.04 (35.1) -
2	KSRT113	4.259 (4.6) -
3	BLANK	<.0200 ✓
4	SH-4676	82.29
5	SH-4677	102.3
6	SH-4694 X10	.5760
7	BLK + SPK	46.27
8	SH-4694 + SPK	44.91
9	CEMENT BLANK	.1772 OK
10	SH-4579 X10	365.3 RPD ✓
11	SH-4579 DUPL	360.0 1.5% ✓
12	SH-4580 X10	521.9 RPD ✓
13	SH-4580 DUPL	536.2 3% ✓
14	SH-4676 DUPL RPD Inst 17%	83.15 ✓
15	KSRICV1	47.64 (50)
16	KSRT109	33.56 (35.4)
17	NBS 1016	1602. RPD ✓
18	NBS 1016 X10	1702. 6% ✓
19	SH-4694	.4043
20	KSRT109	33.99 (35.4) ✓

The precision of the method is good. RPD's low

The NBS SRM recovery is 90% for CaO.

Found = 59% MPV 65%

all values taken from 1:10 dilution - working range of Ca

M.A. Lake

NBS Portland Cement is used as the standard reference to check the method for determination of Cement content in concrete by CaO determination - ASTM C-85.

In all samples + references 2.02g was digested and brought to 500ml volume.

Calc:

$$[Ca]_{mg/L} \times \frac{500}{1000} L \times \frac{1000^{mg}}{2000^{mg}} \times \frac{56.077^{g/mole} CaO}{40.078^{g/mole} Ca} = \frac{mg}{g} \text{ or } \frac{g}{Kg} CaO \times .1 = \% CaO$$

$$\% CaO \times \frac{100}{63.5} = \% \text{ cement} \quad \text{The 63.5 factor is the average CaO content of cements.}$$

$$[Ca] \times .05453 = \% \text{ cement in concrete}$$

# 4579

$$365.3 \times .05453 = 19.92\% \text{ cement in concrete}$$

# 4580

$$521.9 \times .05453 = 28.46\% \text{ cement in concrete}$$

#	Sample Name	File	Method	Date	Time	OpID	Type	Mode
1	KSRT109	ANADATA	ICAP	01/25/94	16:53	MAL	S	CONC
2	KSRT113	ANADATA	ICAP	01/25/94	16:56	MAL	S	CONC
3	BLANK	ANADATA	ICAP	01/25/94	17:00	MAL	S	CONC
4	SH-4676	ANADATA	ICAP	01/25/94	17:03	MAL	S	CONC
5	SH-4677	ANADATA	ICAP	01/25/94	17:06	MAL	S	CONC
6	SH-4694 X10	ANADATA	ICAP	01/25/94	17:09	MAL	S	CONC
7	BLK + SPK	ANADATA	ICAP	01/25/94	17:13	MAL	S	CONC
8	SH-4694 + SPK	ANADATA	ICAP	01/25/94	17:16	MAL	S	CONC
9	CEMENT BLANK	ANADATA	ICAP	01/25/94	17:20	MAL	S	CONC
10	SH-4579 X10	ANADATA	ICAP	01/25/94	17:23	MAL	S	CONC
11	SH-4579 DUPL	ANADATA	ICAP	01/25/94	17:26	MAL	S	CONC
12	SH-4580 X10	ANADATA	ICAP	01/25/94	17:30	MAL	S	CONC
13	SH-4580 DUPL	ANADATA	ICAP	01/25/94	17:33	MAL	S	CONC
14	SH-4676 DUPL	ANADATA	ICAP	01/25/94	17:37	MAL	S	CONC
15	KSRTCV1	ANADATA	ICAP	01/25/94	17:41	MAL	S	CONC
16	KSRT109	ANADATA	ICAP	01/25/94	17:44	MAL	S	CONC
17	NBS 1016	ANADATA	ICAP	01/25/94	17:47	MAL	S	CONC
18	NBS 1016 X10	ANADATA	ICAP	01/25/94	17:54	MAL	S	CONC
19	SH-4694	ANADATA	ICAP	01/25/94	17:59	MAL	S	CONC
20	KSRT109	ANADATA	ICAP	01/25/94	18:03	MAL	S	CONC



# Certificate of Analysis

STANDARD SAMPLE 1016  
PORTLAND CEMENT

	<u>Percent</u>
SiO <sub>2</sub> -----	21.0 <sub>5</sub>
Al <sub>2</sub> O <sub>3</sub> -----	4.97
Fe <sub>2</sub> O <sub>3</sub> -----	3.71
TiO <sub>2</sub> -----	0.34
P <sub>2</sub> O <sub>5</sub> -----	.13
CaO (+SrO) -----	65.2 <sub>6</sub>
SrO -----	0.25
MgO -----	.42
SO <sub>3</sub> -----	2.27
Mn <sub>2</sub> O <sub>3</sub> -----	0.04
Na <sub>2</sub> O -----	.55
K <sub>2</sub> O -----	.04
Li <sub>2</sub> O -----	(.012)
Rb <sub>2</sub> O -----	* (N.D.)
Loss on Ignition -----	1.20

Values in parentheses are not certified but are given as added information.

\*N.D. = not detected, but less than 0.001%

A. A. Bates, Chief  
Building Research Division

Washington, D. C.  
Revised Certificate April 24, 1964  
Original Certificate January 17, 1962  
Certificate Reprinted January 17, 1969

USCOMM-NBS-DC



### **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.