R-94-06

DESCHUTES—CANAL-LINING DEMONSTRATION PROJECT

CONSTRUCTION REPORT

Upper Deschutes River Basin Water Conservation Program

May 1994

U.S. DEPARTMENT OF THE INTERIOR
Bureau of Reclamation

Pacific Northwest Regional Office
Planning Program and Development Office

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16. ABSTRACT

In an endeavor to develop and implement an effective water conservation strategy in the Deschutes River Basin in central Oregon, the Bureau of Reclamation constructed 18 canal-lining demonstration test sections to assess effectiveness in reducing seepage. The area's volcanic geology contributes to high seepage rates, and canals typically consist of fractured basalt bottoms and sides of soil and rock. Ponding tests showed that seepage rates were reduced by 1 to 2 orders of magnitude.

The lining systems were specially designed to accommodate the severe angular subgrade and included combinations of geosynthetics, soil, concrete, elastomeric coatings, and sprayed-in-place foam. Each test section covered between 15,000 and 30,000 ft^2. This report documents the construction phase and details construction materials, techniques, costs, and initial water savings. Estimates of durability, design life, maintenance costs, life-cycle costs, and long-term costs of conserved water are also discussed. Future reports will further evaluate these long-term factors. The reports provide useful information relative to canal lining performance and cost that can be used to develop site-specific water conservation strategies.

This demonstration project is a cooperative effort between the Bureau of Reclamation, the Oregon Water Resources Department, the Upper Deschutes River Basin irrigation districts, and several geosynthetic lining manufacturers.

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Upper Deschutes River Basin Water Conservation Project

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May 1994

UNITED STATES DEPARTMENT OF THE INTERIOR ★ **BUREAU OF RECLAMATION**

ACKNOWLEDGMENTS

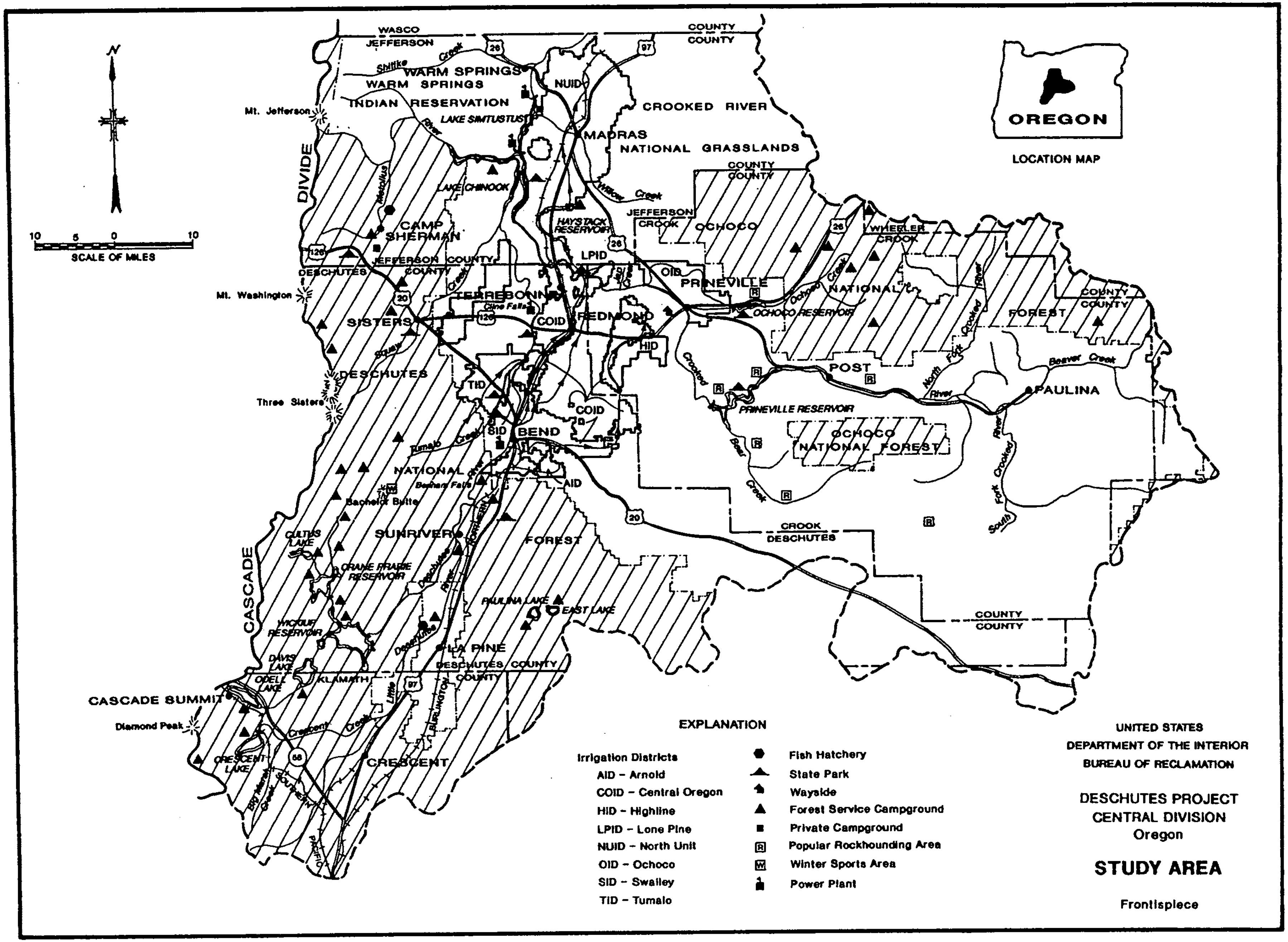
Reclamation acknowledges the support of the irrigation community in central Oregon, which was essential to plan and implement the demonstration project. Reclamation particularly appreciates the support from the boards of directors of the Arnold and North Unit Irrigation Districts. Water user support consisted of both a financial commitment and the acceptance of the risks involved with testing unfamiliar technologies.

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 for those products.

Several people within Reclamation performed key roles in the demonstration project and merit recognition. Eric Glover, team leader for the Upper Deschutes River Basin Water Enhancement Project, helped conceive the idea for the demonstration project, developed the research plan, worked with the water users to scope the project and select the test sites, arranged for most of Reclamation's financial contribution, and served as the research program manager for the first two years. Sam Stivison and Tino Tafoya from the Pacific Northwest Regional Office negotiated and executed the construction contracts, and Peggy Nelson from the Bend Construction Office helped with contract administration. Tom Hess, Jim Lawrence, and Jim Peters from the Bend Construction Office provided construction inspection services and documented the construction on video tape. Keith Campbell, now retired, and Roger Burnett from the Denver Office were responsible for the pre- and post-construction seepage tests. Bill Morrison, now retired, was the Denver Office principal investigator at the start of this study, worked with the water users to select the test sites, contacted the material suppliers, and solicited submittal of their proposals. And last, but not least, Dianne Clark and Tom Hovland of the Denver Office provided technical writing and editing services to the authors.

U.S. Department of the Interior
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.



Frontispiece map. — Study area.

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PHOTOGRAPHS — CONTINUED

SUMMARY

This report describes the results of a canal-lining demonstration project conducted in the Upper Deschutes River basin of central Oregon. The purpose of the demonstration project was to evaluate the effectiveness of different lining materials and construction techniques in reducing seepage from canals with high rates of water loss and severe subgrades. Canals in the area typically lose 35 to 50 percent of their water to seepage because they have fractured basalt bottoms with sides of highly porous soil and rock. Water lost to seepage has not been detected in returns either to the river or to a readily usable ground-water aquifer. For all practical purposes, the water is completely lost for beneficial uses in the Upper Deschutes River basin.

The demonstration project is a cooperative effort among the Bureau of Reclamation (Reclamation), the Oregon Water Resources Department, basin irrigation districts, and several geosynthetic manufacturers. The various participants provided funding, labor, materials, and expertise. The demonstration project supports the UDRBWCP (Upper Deschutes River Basin Water Conservation Project) study, which seeks to reduce water losses in the basin and thereby improve instream flows and critical year irrigation water supplies.

Lining materials and construction techniques were tested on 10 sections of the Arnold Canal and 8 sections of the North Unit Main Canal. Test sections ranged from 300 to 1,000 feet in length and 15,000 to 30,000 square feet (ft^2) in area. This report describes the construction materials (geosynthetics, soil, concrete, shotcrete, elastomeric coatings, and sprayed-in-place foam), their installation, construction costs, and initial water savings. Estimates for the costs of the conserved water, durability, maintenance costs, and life-cycle costs are also discussed.

Ponding tests conducted on the Arnold Canal in 1993, about a year after the linings were installed, showed seepage rates between 0.00 and 0.12 cubic feet per square foot per day ($ft^3/ft^2 \cdot day$), with the majority of the seepage rates less than 0.07 $ft^3/ft^2 \cdot day$. Pre-construction seepage rates were 10 to 100 times higher (0.64 to 4.20 $ft^3/ft^2 \cdot day$).

As a cooperative effort, Reclamation's goal was to equally share with the material suppliers and irrigation districts the field construction costs, including construction, unlisted items, and contingencies. Total construction cost for the demonstration project was $1.9 million, of which suppliers and irrigation districts contributed $0.9 million and Reclamation contributed $1.0 million.

Information generated from this demonstration project will provide data needed to help develop a comprehensive, basin-wide water conservation plan. This project will also provide general information on canal-lining performance and cost. This information may apply to other areas of the Nation where water conveyance systems are constructed through basalt-type rocks or other porous material. Many of the technologies evaluated also have other uses, such as rehabilitation of concrete-lined canals.

Preliminary data from this project indicate that, for canal sections with high seepage rates, canal-lining can save significant amounts of water at a reasonable cost ($10 to $100 per acre-foot).

CHAPTER 1
INTRODUCTION

This report describes the results of a canal-lining demonstration project conducted in the Upper Deschutes River basin of central Oregon. Lining materials and construction techniques were tested on 10 sections of the Arnold Canal and 8 sections of the North Unit Main Canal to evaluate their effectiveness in reducing seepage in areas with severe subgrade conditions. This report describes the materials and applications and provides estimates of water savings and construction costs.

The demonstration project supports the UDRBWCP (Upper Deschutes River Basin Water Conservation Project) study, a cooperative effort among the Bureau of Reclamation (Reclamation), the Oregon Water Resources Department, basin irrigation districts, and lining manufacturers. The UDRBWCP study area consists of the Deschutes River basin above Lake Billy Chinook, including the Crooked River basin, up to existing headwater storage reservoirs (frontispiece map).

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 in critical water years. Improved flows would protect and enhance recreation and fish and wildlife. The overall UDRBWCP study addresses distribution system efficiencies, onfarm efficiencies, and operating efficiencies. This canal-lining demonstration project addresses distribution system efficiencies.

Background

The area's volcanic geology contributes to high seepage rates. Canals in the area typically lose 35 to 50 percent of their water to seepage because they have fractured basalt bottoms with sides of highly porous soil or soil and rock. The fractured basalt subgrade material also hinders excavation in the canal prism. Therefore, specialized lining technologies are needed to reduce seepage in these areas. Special emphasis was placed on geomembrane liners because they are relatively immune to freeze/thaw degradation, and therefore should provide an effective long-term seepage barrier.

Arnold and North Unit Main Canals in the Bend-Redmond area (figure 1) are generally excavated in basalt or ash flow tuffs exhibiting various degrees of fracturing (Gilbert and Carter, 1991). Canals in the Redmond-Madras area are excavated in basin fill deposits. An exception is the Ochoco Feed Canal, which is founded primarily on fan deposits derived from older volcanic rocks. Photographs 1-8 show subgrade conditions on Arnold and North Unit Main Canals.

For this demonstration project, two geotechnical factors were assessed for canals in the study area: (1) relative permeability of foundation materials and (2) suitability for canal-lining. Limited irrigation district records show that some areas have experienced large losses into "sinkholes" in the past. Present operations suggest that the highest losses are in those canals constructed in basalt.

Before the test linings were installed, ponding tests were conducted (in March 1991) to determine rates of seepage. Average seepage rates measured on three canal sections were 0.64, 1.40, and 4.20 $ft^3/ft^2 \cdot day$. These seepage rates are one to two orders of magnitude greater than the accepted seepage rate of 0.07 $ft^3/ft^2 \cdot day$ for a well-constructed concrete-lined canal.

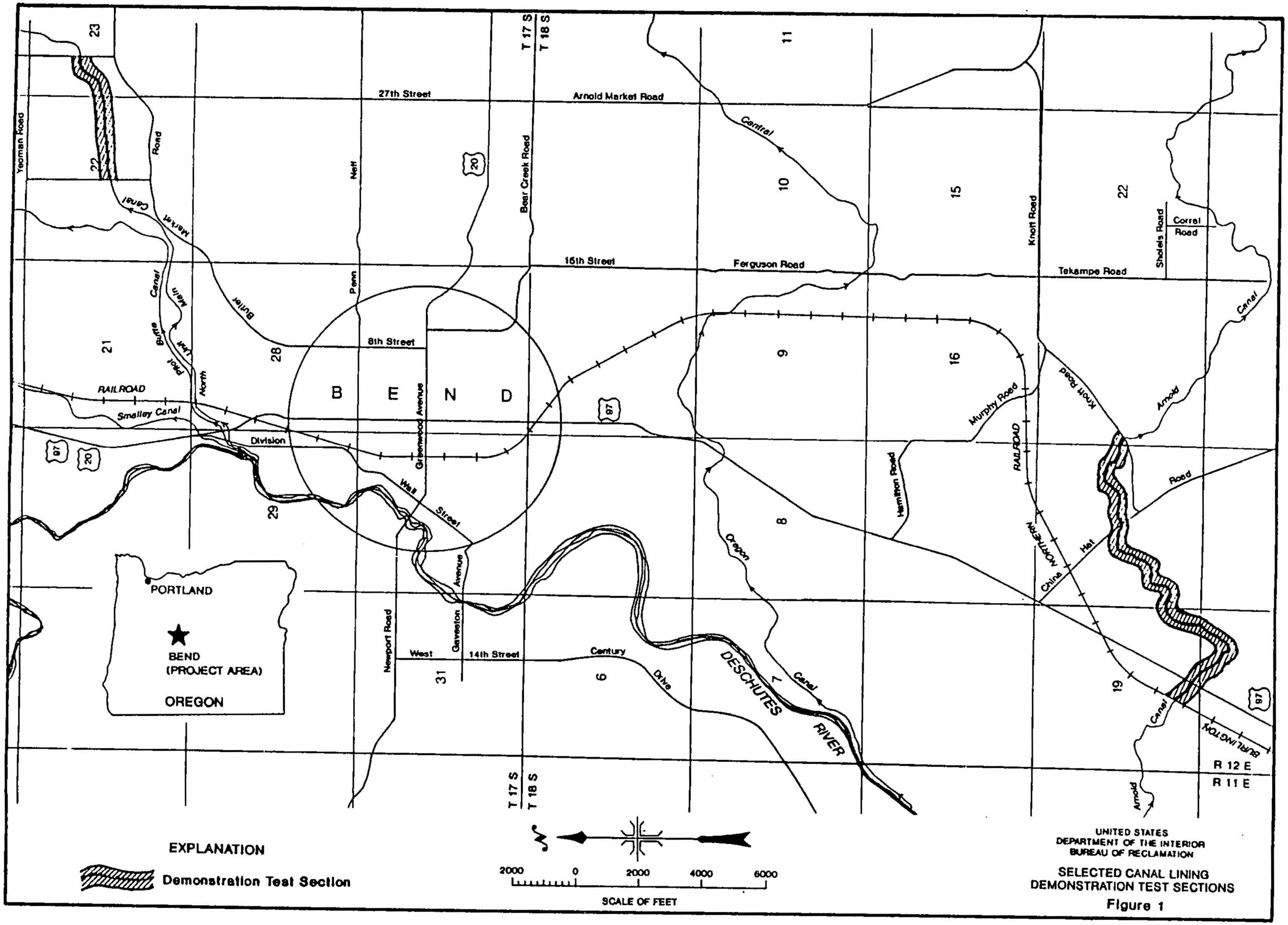


Figure 1. — Location of demonstration project test sections.

Arnold Canal
General Subgrade Conditions

Photograph 1. — Section of canal with natural sediment deposits and rock side slopes.

Photograph 2. — Sections of canal with rock and stumps requiring removal.

Arnold Canal
General Subgrade Conditions

Photograph 3. — Section of canal with loose overhangs that need removal.

Photograph 4. — Section of canal with fractured rock.

North Unit Main Canal
General Subgrade Conditions

Photograph 5. — Section of canal with natural sediment deposits.

Photograph 6. — Section of canal with fractured rock.

North Unit Main Canal
General Subgrade Conditions

Photograph 7. — Section of canal with rock that can only be removed by blasting.

Photograph 8. — Section of canal with natural drop that creates high velocities.

Proposals

Prospective suppliers of canal-lining materials were contacted by direct mail and through a notice in the *Commerce Business Daily* (see appendix A). All 20 proposals received were evaluated in a two-step process: a technical evaluation followed by a cost evaluation.

Technical Evaluation. —

A three-person TEC (technical evaluation committee) evaluated each proposal based on three criteria: technical (50 percent), capability (25 percent), and new materials and applications (25 percent). Sample worksheets for the technical evaluation are located in appendix A.

Each evaluator independently scored the proposal for the three criteria on a scale of 1 to 5. Following the independent evaluation, the TEC met to discuss ratings for each proposal. At that time, each evaluator could choose to stay with the original score or change ratings. Total points for any proposal from each evaluator ranged between 3 and 15 points. The total evaluation score consisted of the sum of the three evaluators' scores. The scores for each proposal were used to rank order the proposals from highest (first priority) to lowest (last priority). Composite scores for the technical evaluation are located in appendix A. Any proposal receiving a total score of less than 6 for any of the three criteria was eliminated from further consideration.

Cost Evaluation. —

Based on the information presented in each proposal, Reclamation developed the following costs (1991 dollars):

(1) the cost of Reclamation supplied materials, equipment, and labor; and
(2) the cost of materials, equipment, and labor to be provided by the materials supplier and by the affected irrigation district. The cost for contributed resources was based on estimates for Reclamation to acquire those resources in the marketplace.

Reclamation then added the cost information to the rank-ordered list prepared by the TEC. Reclamation's cost was used as the tie-breaker for identical or similar proposals.

Selection Process. —

Nineteen proposals were selected for participation, however, one firm was unable to follow through with their proposal and was dropped from participation. Thus, the total number of test sections installed to date is 18.

Implementation of the canal-lining demonstration has depended upon the availability of funding. First, Reclamation funded those proposals using geosynthetic materials, followed by direct-application proposals such as shotcrete and foam. Geosynthetic materials were favored because they are uniform (manufactured in a controlled environment) and flexible (relatively immune to effects of freeze/thaw), and therefore were believed to be a more effective long-term seepage barrier.

Six prime contractors and fourteen material suppliers contributed lining materials and/or labor. The Arnold Irrigation District, the North Unit Irrigation District, and other irrigation districts within the river basin (figure 2) supplied labor, equipment, and materials for canal subgrade preparation. Tables 1 and 2 list the contractors, material suppliers, and costs, along with the estimated contributions made by each participating entity. The material supplier's contributions include a 35-percent engineering and design surcharge.

Total estimated construction cost for the 18 test sections is $1.9 million. Suppliers and irrigation districts contributed $0.9 million, and Reclamation contributed the remaining $1.0 million, nearly achieving the goal of a 50/50 cost share. Unit construction costs ($\$/ft^2$) are discussed in chapter 2.

Future Work and Applications

Information generated from this demonstration project will provide data needed to help develop a comprehensive, basin-wide water conservation plan. The project will also provide general information on canal-lining performance and cost. This information may apply to other areas where water conveyance systems are constructed through basalt-type rocks or other angular porous material. Future work on the 18 Arnold and North Unit test sections will include:

1) determining lining durability,
2) documenting maintenance and repair costs,
3) assessing long-term seepage rates, and
4) calculating life-cycle costs.

Future work involving additional test sections will concentrate on several areas, including:

1) rehabilitating existing lining materials,
2) installing non-specialty liners (installed by irrigation districts, using their own forces),
3) testing other subgrade conditions,
4) testing lining technologies significantly different than those tested to date, and
5) refining promising lining technologies.

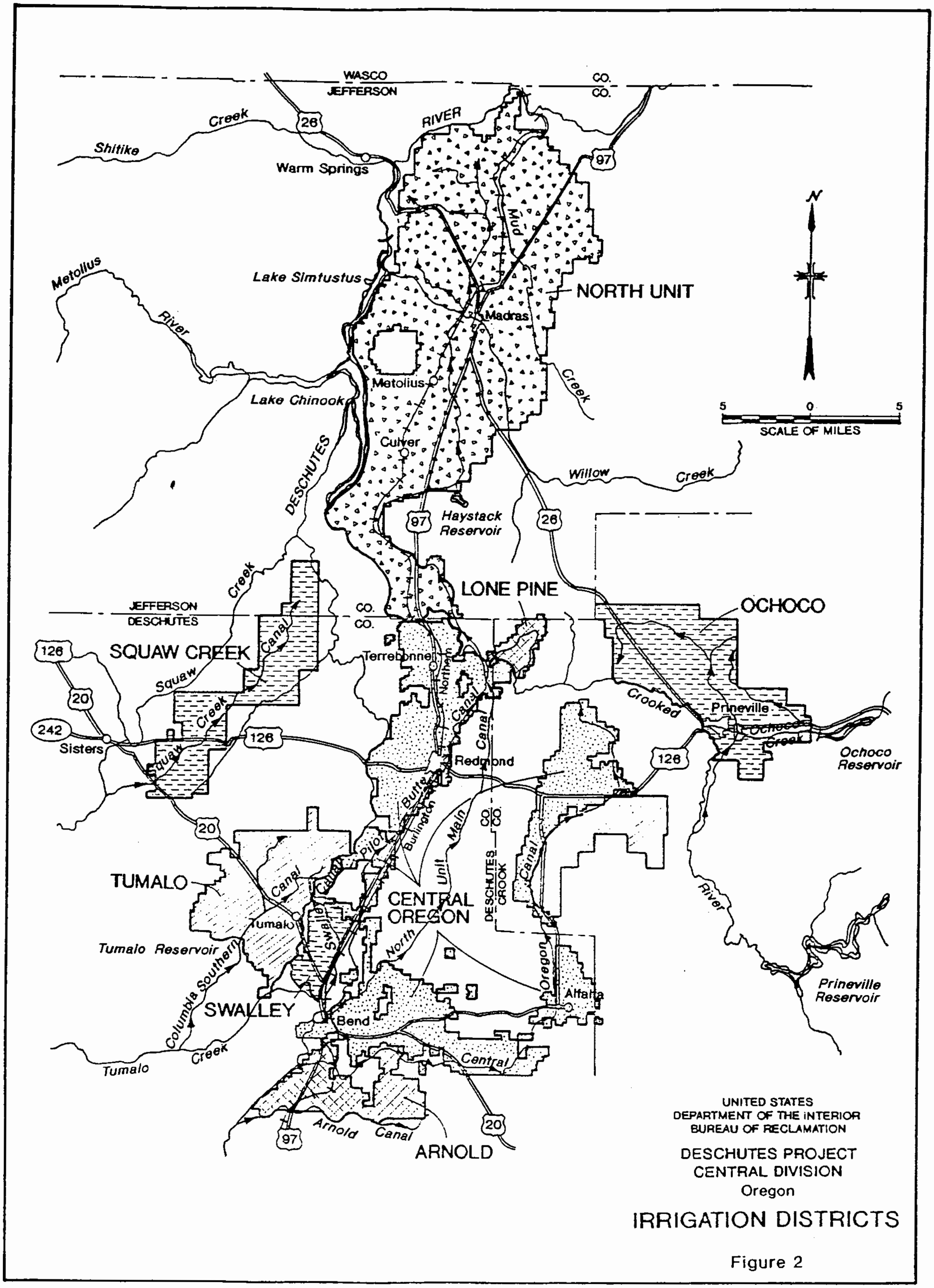


Figure 2. — Locations of the irrigation districts.

Table 1. — Arnold Irrigation District: canal-lining demonstration project.

Prime contractor	Material suppliers	Total cost (estimate)	Reclamation contract cost	Arnold Irrigation District contribution	Material supplier contribution	Percent district and supplier contribution
Johnson Western Gunite	Phillips Fibers Corporation	$131,000	$80,437	$5,400	$45,163	38.6
Johnson Western Gunite	Gundle Lining Systems Polyfelt Inc.	80,500	55,000	2,500	23,000	31.7
Johnson Western Gunite	Gundle Lining Systems	50,000	34,580	2,300	13,120	30.8
Environmental Liners	Occidental Chemical Corporation Trevira Corporation	55,000	30,000	2,500	22,500	45.4
Environmental Liners	JP Stevens Elastomerics Polyfelt Inc.	50,000	10,000	2,300	37,700	80.0
Environmental Liners	JP Stevens Elastomerics Polyfelt Inc.	45,000	5,051	5,700	34,249	88.8
Pacific Erosion Control	Occidental Chemical Corporation Nicolon Corporation	202,000	97,045	1,000	103,955	52.0
Canamer International	Nicolon Corporation	101,000	61,832	1,500	37,668	38.8
Canamer International	Nicolon Corporation Poly-Flex Inc. Amoco Fabrics & Fibers	262,000	96,163	1,500	164,337	63.3
Canamer International	Nicolon Corporation Poly-Flex Inc. Amoco Fabrics & Fibers	262,000	110,262	2,000	149,738	57.9
	Total	$1,238,500	$580,370	$26,700	$631,430	53.1

Table 2. — North Unit Irrigation District: canal lining demonstration project.

Prime contractor	Material suppliers	Total cost (estimate)	Reclamation contract cost	North Unit Irrigation District contribution	Material supplier contribution	Percent district and supplier contribution
Holton Enterprises Inc.	Montana Urethane Systems Supply Futura Coatings Inc.	$131,000	$50, 000	$1,000	$80,000	61.8
Holton Enterprises Inc.	Montana Urethane Systems Supply Futura Coatings Inc.	80,500	44,148	1,000	35,352	45.2
Holton Enterprises Inc.	Montana Urethane Systems Supply Futura Coatings Inc. Tietex Corporation	50,000	38,000	1,000	11,000	24.0
Holton Enterprises Inc.	Montana Urethane Systems Supply Futura Coatings Inc. Phillips Fibers Corporation	55,000	39,849	1,000	14,151	27.5
Johnson Western Gunite	Novocon International Corporation	96,000	75,415	500	20,085	21.4
Johnson Western Gunite	Phillips Fibers Corporation	95,000	59,034	500	35,466	37.9
Johnson Western Gunite	Fibermesh Co.	94,000	57,635	500	35,865	38.7
Johnson Western Gunite	Johnson Western Gunite Co.	85,000	60,000	500	24,500	29.4
	Total	$686,500	$424,081	$6,000	$256,419	38.2

CHAPTER 2
INSTALLATION OF LINING MATERIALS

General

Different lining materials were installed on 10 sections of the Arnold Canal and 8 sections of the North Unit Main Canal. Each test section ranged from 300 to 1,000 feet in length and 15,000 to 30,000 square feet in area to simulate actual, full-scale installation conditions. However, as construction began, material suppliers and the prime contractor asked to test variations of materials within their assigned section. Figures 3 and 4 list the prime contractor, material supplier, product installed, and show the location of each material installation. The linings were installed over a 17-month period, from November 1991 to March 1993. All test applications will remain in place indefinitely and will become the property of the respective irrigation district. The districts will assume operation, maintenance, and replacement costs and post-construction liability.

Contractors were instructed to install test sections with "minimal" subgrade preparation. However, actual subgrade preparation differed widely among contractors and material suppliers. The costs of subgrade preparation are included in the unit costs for each lining technology. Subgrade preparation and associated cost for each test section are defined as follows:

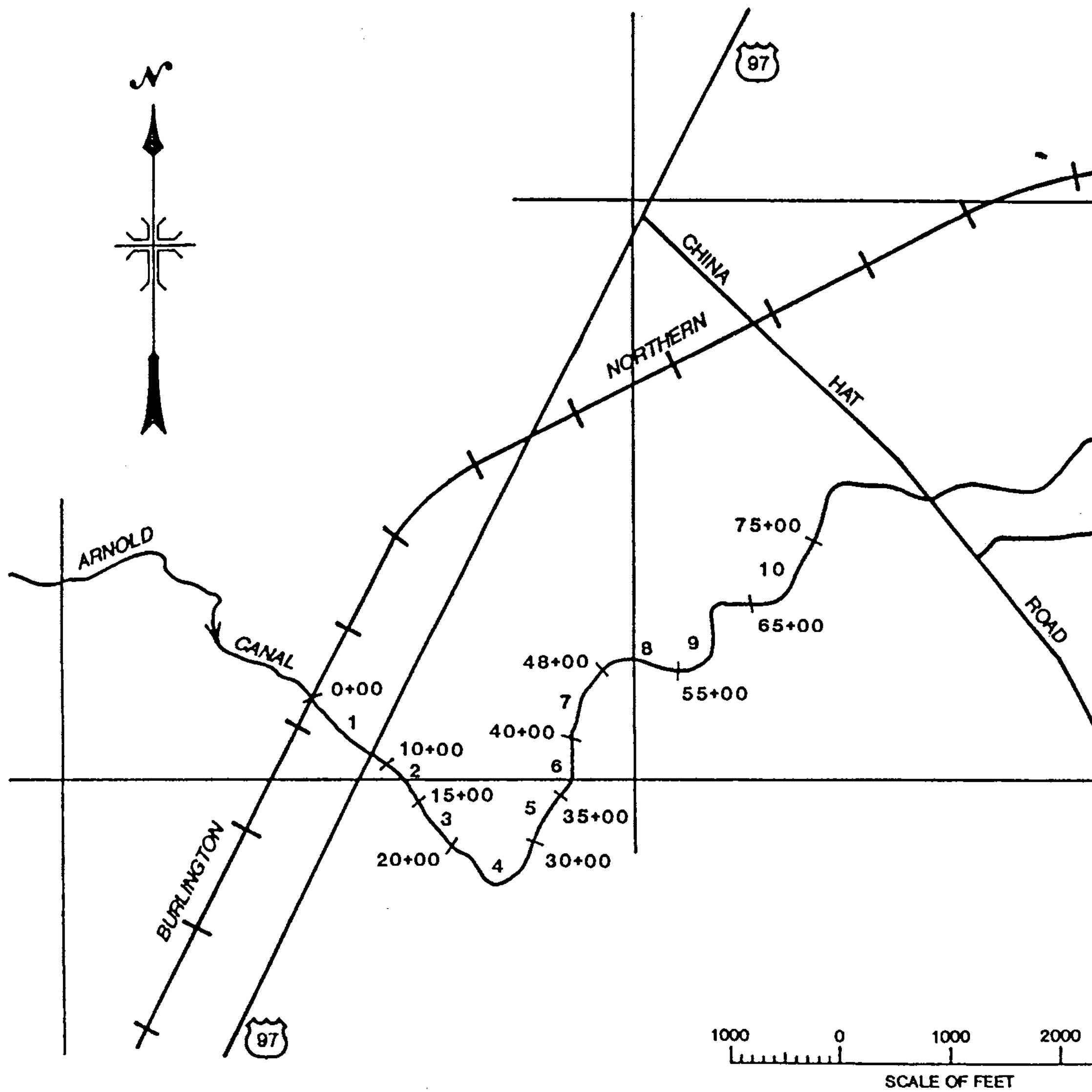
- None - Material laid over existing subgrade (cost of $0.00/ft^2).
- Minimal - Removal of large, loose rock (cost of $0.04/ft^2).
- Moderate - Removal of large loose rock, knock-down of scour overhang on side slopes, and redistribution of existing canal sediment to cover rocky areas (cost of $0.12/ft^2).
- Extensive - Removal of large loose rock, knock-down of scour overhang on side slopes, and redistribution of canal sediment. Also included placement of 1 to 2 inches of imported fill material over rocky areas (cost of $0.26/ft^2).

The irrigation districts requested some additional subgrade work to remove rock outcroppings in the canal bottom at existing flow constrictions. This work was typically performed with a backhoe-mounted rock hammer. The contractors were paid for this additional work, but the costs were not used to calculate test section unit costs. Appendix B includes subgrade preparation cost estimates.

Unit Costs of Materials

At this point, the alternative lining materials and installations can only be compared on the basis of initial construction costs. However, a truly meaningful comparison should be based on both effectiveness (long-term seepage) and life-cycle costs. Life-cycle costs include not only initial construction costs, but also maintenance costs and design life (durability). The effectiveness and durability of these linings will be addressed in a series of "durability reports" to be published over the next 5 to 10 years. The first durability report (covering 1 to 2 years of service) is currently being prepared and will be available by fall 1994. However, chapter 5 of this report makes some conservative generalizations regarding maintenance costs, design lives, and long-term seepage rates to estimate the costs of conserved water.

Table 3 summarizes the unit construction costs for each test section. The costs are based on contractor and Reclamation estimates for a large job to line 100,000 square feet or more. Costs include labor, equipment, materials, overhead, and profit. Costs not included are design costs, contingencies, and unlisted items, as well as allowances for remote job sites, cold weather, and limited access.



SECTION	PRIME CONTRACTOR & MATERIAL SUPPLIERS	MATERIAL
1	Johnson Western Gunite San Leandro, CA Phillips Fibers Corp.	Petromat MBII with 3-inch shotcrete cover
2	Johnson Western Gunite San Leandro, CA Gundle Lining Systems Inc. Polyfelt Inc.	30-mil textured VLDPE on a 16-ounce geotextile cushion with 3-inch shotcrete cover
3	Johnson Western Gunite San Leandro, CA Gundle Lining Systems Inc.	Exposed 60-mil textured HDPE
4	Environmental Liners Inc. Cortez, CO Occidental Chemical Corp. Trevera Corp.	Inverted Geolam on a 6-ounce geotextile cushion
5	Environmental Liners Inc. Cortez, CO JP Stevens Elastomerics Polyfelt Inc.	Exposed 45-mil Hypalon on a 16-ounce geotextile cushion
6	Environmental Liners Inc. Cortez, CO JP Stevens Elastomerics	Exposed 36-mil Terra-Tuff geomembrane
7	Pacific Erosion Control Seattle, WA Occidental Chemical Corp. Nicolon Corp.	40-mil PVC with 3-inch grout-filled mattress
8	Canamer International Inc. Winona, MN Nicolon Corp.	3-inch Grout-Filled Mattress (Uniform Section Mat)
9	Canamer International Inc. Winona, MN Nicolon Corp. Poly-Flex Inc. Amoco Fabrics & Fibers Co.	Exposed 60-mil VLDPE on a 12-ounce geotextile cushion with 3-inch grout-filled mattress on side slopes only
10	Canamer International Inc. Winona, MN Nicolon Corp. Poly-Flex Inc. Amoco Fabrics & Fibers Co.	Exposed 60-mil HDPE on a 12-ounce geotextile cushion with 3-inch grout-filled mattress on side slopes only

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UPPER DESCHUTES RIVER BASIN,
WATER CONSERVATION PROJECT - OREGON

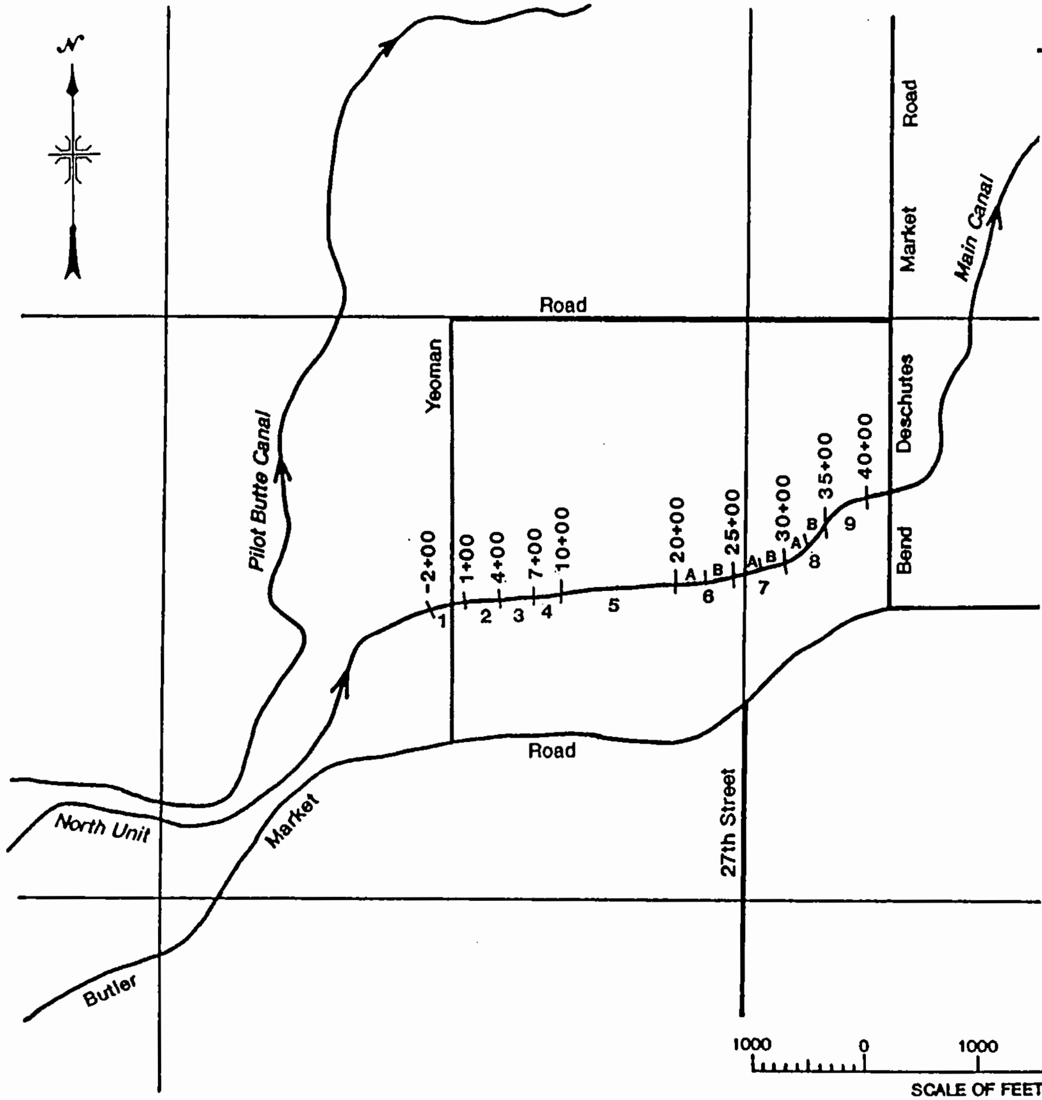
LOCATION MAP

ARNOLD CANAL

DENVER, COLORADO — MAY 1991

Figure 3

Figure 3. — Arnold Canal location map.



SECTION	PRIME CONTRACTOR & MATERIAL SUPPLIERS	MATERIALS
1	Holton Enterprises Inc. Boise, Idaho Montana Urethane Systems Supply Futura Coatings Inc.	Spray-applied polyurethane foam with Futura 500/550 protective coatings
2	Holton Enterprises Inc. Boise, Idaho Montana Urethane Systems Supply Futura Coatings Inc.	Spray-applied polyurethane foam with Geothane 5020 protective coating
3	Holton Enterprises Inc. Boise, Idaho Montana Urethane Systems Supply Futura Coatings Inc. Tietex Corp.	Tietex geotextile with sprayed-applied Geothane 5020 protective coating
4	Holton Enterprises Inc. Boise, Idaho Montana Urethane Systems Supply Futura Coatings Inc. Phillips Fibers Corp.	Phillips geotextile with sprayed-applied Geothane 5020 protective coating
5	NONE	
6	Johnson Western Gunite Co. San Leandro, CA Novocon International Corp.	A. 3-inch shotcrete reinforced with steel fibers (50 pounds per cubic yard) B. (25 pounds per cubic yard)
7	Johnson Western Gunite Co. San Leandro, CA Phillips Fibers Corp.	A. 3-inch shotcrete reinforced with polyfibers (3 pounds per cubic yard) B. (1-1/2 pounds per cubic yard)
8	Johnson Western Gunite Co. San Leandro, CA Fibermesh Co.	A. 3-inch shotcrete reinforced with polyfibers (3 pounds per cubic yard) B. (1-1/2 pounds per cubic yard)
9	Johnson Western Gunite Co. San Leandro, CA	3-inch unreinforced shotcrete

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WATER CONSERVATION PROJECT – OREGON

LOCATION MAP

NORTH UNIT MAIN CANAL

DENVER, COLORADO JUNE 1991

Figure 4

Figure 4. — North Unit Main Canal location map.

Table 3.—Comparison of canal lining costs.

Section No.	Arnold Irrigation District Description	Lining Material: Geomembrane Cost $/sq. ft.	Lining Material: Geotextile Cost $/sq. ft.	Lining Material: Shotcrete Cost $/sq. ft.	Lining Material: Other Cost $/sq. ft.	Lining Material: Total Cost $/sq. ft.	Subgrade Preparation Cost $/sq. ft.	Installation Cost $/sq. ft.	Overhead and Profit %	Total Cost $/sq. ft.
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
Section No.	**North Unit Irrigation District 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.

Arnold Canal

The Arnold Irrigation District, first organized in 1905, diverts water from the Deschutes River a few miles south of Bend, Oregon, and provides water for 4,292 acres of irrigable land. Main project features include the Arnold Diversion Dam, Arnold Flume (1½ miles long), Arnold Canal (11 miles long), and about 25 miles of laterals. The water supply comes from natural flow, and is supplemented by storage from the Crane Prairie Reservoir. The Arnold Canal averages about 30 feet wide and 3 feet deep. Flow capacity is about 140 cubic feet per second (ft^3/s) at the diversion.

All ten test linings installed on the Arnold Canal used various geomembrane liners. Several of the linings included either a shotcrete cover or a grout-filled mattress. The Arnold Canal has a smaller cross-section and more bottom sediment (sandy-silty material) than the North Unit Canal. Therefore, lining technologies requiring greater subgrade preparation (i.e., geosynthetics) were installed on the Arnold Canal. Lining technologies requiring less subgrade preparation (such as shotcrete and sprayed-in-place foam) were installed on the North Unit Canal. Appendix C contains the manufacturers' data sheets for the linings installed on the Arnold Canal.

Test Section 1. —

Material:	Petromat MB II (Geoseal) with 3-inch shotcrete cover
Date installed:	February 1992
Location:	Station 0+00 to 10+00 (1,000 linear feet; 30,000 square feet)
Description:	Petromat MB II is a 4-mil polyethylene geomembrane with a 4-ounce non-woven geotextile bonded to each side. The 3-inch-thick shotcrete cover was applied by the wet-mix process using 7-sack pea-gravel pump mix (94 lb of cement per sack, ⅜-in maximum aggregate size). The first 500-foot section contained 1½ pounds of Phillips fibermesh polypropylene fibers per cubic yard (lb/yd^3). The second 500-foot section contained unreinforced shotcrete.
Prime Contractor:	Johnson Western Gunite Co.
Material Supplier:	Phillips Fibers Corporation
Subgrade Preparation:	Moderate/extensive subgrade preparation was performed to smooth out the canal subgrade so that the lining would not be damaged. Loose boulders were removed, and 1 to 2 inches of imported crushed volcanic cinders were placed on the rocky side slopes. The canal bottom was already covered with 1 to 2 inches of sediment and did not require any additional bedding.
Construction:	The lining was installed in 12-foot-wide strips across the canal. The strips were overlapped 2 feet in the direction of the canal flow. The joints were overlapped but not seamed, and were weighted down to the subgrade and the sides until the shotcrete was applied. The shotcrete was applied over the lining at an average thickness of 3 inches up to the waterline and feathered out 6 to 12 inches beyond the edge of the synthetic lining. Anchor trenches were not required to hold the lining in place. The shotcrete was sprayed with curing compound and covered with light tarps for 3 days to prevent freezing.
Difficulties:	Installers had difficulty applying a uniform layer of shotcrete, a common problem with all shotcrete applications over irregular subgrades. The irregular shotcrete thickness is not in itself detrimental; however, it increases the chance for thin spots that will need repair in the future. Shotcrete thicknesses on the Arnold Canal are probably more uniform than on the North Unit Main Canal because the geomembrane liners tend to even out the irregular subgrade.
Unit cost estimate:	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

Advantages:	The geocomposite allowed the geotextile cushion and geomembrane to be installed as one piece. Installation was also made easier because the seams were not sealed. The shotcrete cover will provide a hard, durable surface, and will allow operation of maintenance equipment in the canal. The shotcrete is expected to crack with time, but the Petromat geomembrane will maintain positive seepage control.
Disadvantages:	Some seepage may occur through the seams because the Petromat geomembrane was overlapped but not seamed. Adhesive or hot-asphalt seaming should be considered for future applications. Also, the Petromat, which only has a 4-mil geomembrane, may be more susceptible to damage than some of the thicker geomembranes.
Photographs:	9 through 12

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

Photograph 9. — Completed canal preparation.

Photograph 10. — Shotcrete is applied over geomembrane.

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

Photograph 11. — Shotcrete is applied to bridge abutment over MB II material.

Photograph 12. — Completed canal section.

Test Section 2. —

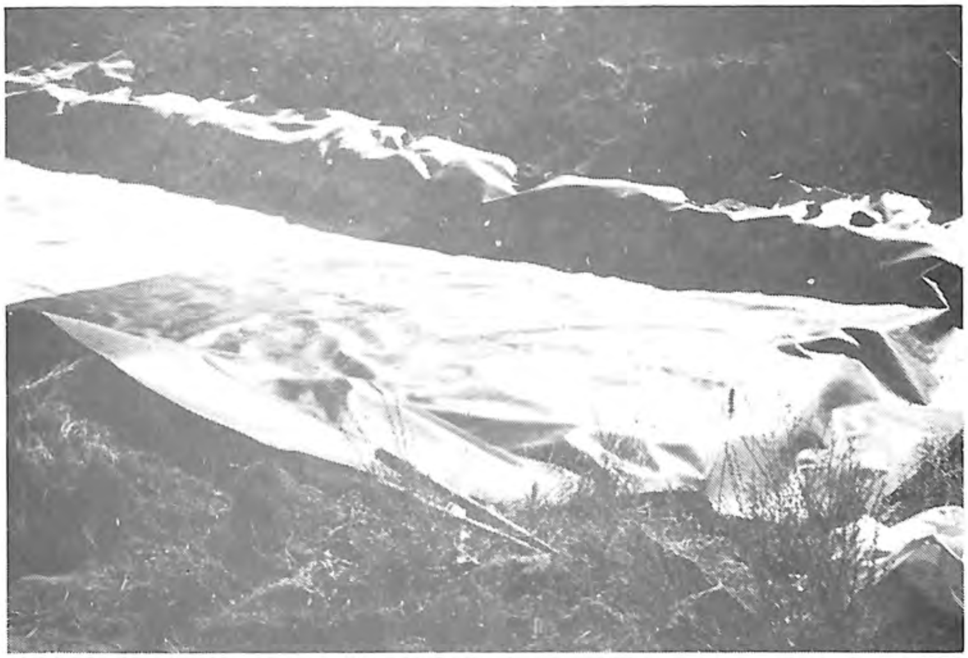
Material:	30-mil textured VLDPE (very low density polyethylene) with 16-ounce geotextile cushion and 3-inch shotcrete cover
Date installed:	October 1992
Location:	Station 10+00 to 15+00 (500 linear feet; 15,000 square feet)
Description:	VLDPE liner is 30-mil Gundle textured Hyperlastic. Geotextile cushion is Polyfelt TS-1000, a 16-ounce, needle-punched, nonwoven geotextile. The 3-inch unreinforced shotcrete cover was applied by the wet-mix process using 7-sack pea-gravel pump mix (94 lb of cement per sack, ⅜-in maximum aggregate size).
Prime Contractor:	Johnson Western Gunite Co.
Material Suppliers:	Gundle Lining Systems Inc. Polyfelt Inc.
Subgrade Preparation:	Extensive subgrade preparation was required to smooth out the existing canal subgrade to meet the requirements of the lining supplier. Large obstructions were removed using a hoe-ram, backhoe, skid steer loader, and hand labor. More than 100 yards of volcanic cinders (½-in maximum aggregate size) were imported and spread on the subgrade, including the side slopes, to provide about 2 inches of bedding for the liner.
Construction:	First, the geotextile cushion was placed and lapped. The 30-mil lining was cut and trimmed to fit the canal section, and the joints were wedge-welded together. A shallow anchor trench was dug (scraped) into the rocky soil. The shotcrete cover was then applied at a rate of about 10,000 ft^2/day. The completed shotcrete lining was sprayed with curing compound and covered with light tarps for 3 days to prevent freezing.
Difficulties:	Installers had difficulty applying a uniform layer of shotcrete, a common problem with all shotcrete applications over irregular subgrades. The irregular shotcrete thickness is not in itself detrimental; however, it increases the chance of thin spots that will need repair in the future. Shotcrete on the Arnold Canal probably has more uniform thickness than North Unit because the geomembrane liners tend to even out the irregular subgrade.
Unit cost estimate:	$2.14 per square foot
Advantages:	The welded seams should provide a watertight installation. Also, the VLDPE is more flexible (easier to handle) than HDPE (high density polyethylene) and thicker (more damage resistant) than Petromat.
Disadvantages:	VLDPE has a large coefficient of thermal expansion, which presents special challenges during construction.
Photographs:	13 through 18

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

Photograph 13. — Bobcat is used to prepare subgrade side slopes.

Photograph 14. — Completed subgrade preparation.

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



Photograph 15. — Geotextile in place over prepared subgrade.

Photograph 16. — Geomembrane is seamed with hot-wedge welder.

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

Photograph 17. — Shotcrete is applied over geomembrane.

Photograph 18. — Completed canal section in background. Geomembrane awaiting shotcrete cover in foreground.

Test Section 3. —

Material:	Exposed 80-mil textured HDPE (high density polyethylene)
Date installed:	October 1992
Location:	Station 15+00 to 20+00 (500 linear feet; 15,000 square feet)
Description:	HDPE liner is black, 80-mil textured Gundline HDT.
Prime Contractor:	Johnson Western Gunite Co.
Material Supplier:	Gundle Lining Systems Inc.
Subgrade Preparation:	Extensive subgrade preparation smoothed out the existing canal subgrade to meet the lining supplier's requirements. Large obstructions were removed with a hoe-ram, backhoe, skid steer loader, and hand labor. More than 100 yards of volcanic cinder (½-in maximum aggregate size) were imported and spread on the subgrade, including the slopes, to provide 1 to 2 inches of bedding for the liner.
Construction:	The lining, which was supplied in a 22-foot wide roll, was placed across the canal, trimmed to fit, seamed with a hot-wedge welder, and buried in a shallow anchor trench which had been scraped into the rocky soil. Where the lining went through an existing box bridge, metal batten strips were installed to anchor the lining to the concrete walls. A 16-ounce nonwoven geotextile was placed under the geomembrane only in the bridge area because of limited access clearance for placement of bedding material.
Difficulties:	The HDPE is quite stiff and difficult to handle during installation.
Unit cost estimate:	$1.38 per square foot
Advantages:	An exposed liner is simpler and less expensive to install than a liner requiring a shotcrete cover. HDPE is inert to many chemicals and offers excellent weatherability.
Disadvantages:	All exposed geomembranes are susceptible to vandalism and animal damage, limit the operation of maintenance equipment in the canal, undergo thermal expansion and contraction (to varying degrees), and are subject uplift if not anchored in the invert. In addition, repair of the exposed HDPE requires purchase of an extrusion welder (about $7,000 new).
Photographs:	19 through 24

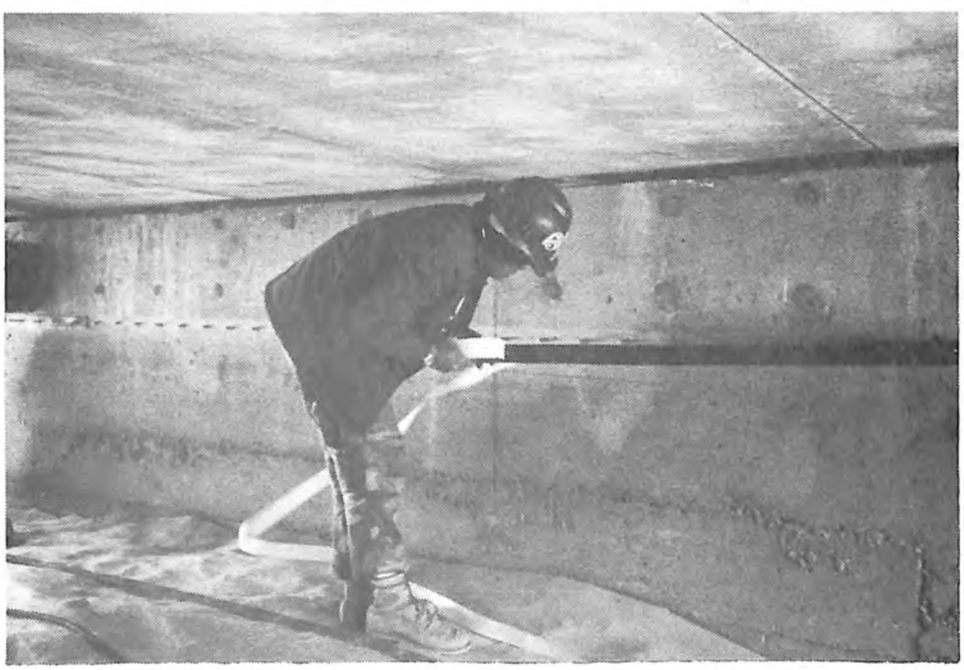
Arnold Canal
Test Section 3
Exposed 80-mil textured HDPE

Photograph 19. — Completed canal preparation.

Photograph 20. — Five-man crew installs geomembrane.

Arnold Canal
Test Section 3
Exposed 80-mil textured HDPE

Photograph 21. — Geomembrane is repaired with a rounded patch and extrusion weld.



Photograph 22. — Stainless steel batten strips are used to attach geomembrane to bridge abutment.

Arnold Canal
Test Section 3
Exposed 80-mil textured HDPE

Photograph 23. — Completed seaming and attachment to bridge.

Photograph 24. — Completed canal section.

Test Section 4. —

Material:	Inverted Geolam with 6-ounce geotextile cushion
Date installed:	March 1992
Location:	Station 20+00 to 30+00 (1,000 linear feet; 30,000 square feet)
Description:	Geolam is a PVC (polyvinyl chloride)/geotextile composite consisting of 30-mil PVC geomembrane bonded to a 6-ounce needle-punched, nonwoven geotextile. The geolam was installed with geotextile side up (inverted) to protect the PVC geomembrane from UV (ultraviolet) light. The cushion is Trevira 1120 (6-ounce needle-punched, nonwoven geotextile).
Prime Contractor:	Environmental Liners Inc.
Material Suppliers:	Occidental Chemical Corporation Trevira Corporation
Subgrade Preparation:	The lining supplier performed extensive subgrade preparation. The contractor removed all loose rock, dressed back the slopes, and covered the entire canal cross-section with 2 inches of dirt, which was raked smooth.
Construction:	The geotextile cushion was rolled into place to protect the Geolam geomembrane. The Geolam was installed in prefabricated 35- by 350-foot panels with the geotextile side up for UV protection. Adjoining panels were seamed with solvent adhesive. The panels were anchored in a shallow anchor trench and backfilled with native soil and rock.
Difficulties:	Electric sewing machines could not operate in wet conditions. Therefore, hogrings were used in some areas to seam the geotextile blanket cover. Hogrings must be spaced no more than 2 feet apart to function adequately. Pneumatic sewing was used to repair some unsatisfactory "hogring" seams. Some of the geotextile cover still needs to be seamed.
Unit cost estimate:	$1.05 per square foot
Advantages:	This system is easy to install, including the solvent seams. An exposed thin PVC membrane is unusual because of the adverse effect of sunlight. If the geotextile successfully protects the PVC geomembrane from UV light, this test section will provide the geomembrane industry with a new installation option. An advantage over exposed HDPE or Hypalon is that the PVC geomembrane is easy to repair by solvent seaming.
Disadvantages:	All exposed geomembranes are susceptible to vandalism and animal damage, limit the operation of maintenance equipment in the canal, undergo thermal expansion and contraction (to varying degrees), and are subject to uplift if not anchored in the invert. In addition, an exposed, thin PVC geomembrane must be protected from UV light. The geotextile layer will initially provide this protection, but the geotextile is also sensitive to UV light and will degrade with time.
Photographs:	25 through 30

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

Photograph 25. — Canal is ready for final smoothing by hand raking.
Tree stump on right bank was outside the canal prism and was left in place.

Photograph 26. — Ten-man crew smooths canal bottom.
Imported subgrade material is shown on right.

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

Photograph 27. — Canal prism is complete and ready for installation of geotextile and Geolam.

Photograph 28. — Geotextile is laid on canal bottom and side slopes.

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

Photograph 29. — Inverted Geolam is placed over geotextile cushion.

Photograph 30. — Completed canal reach after one season of use.

Test Section 5. —

Material:	Exposed 45-mil Hypalon (reinforced) membrane with 16-ounce geotextile cushion
Date installed:	March 1992
Location:	Station 30+00 to 35+00 (500 linear feet; 15,000 square feet)
Description:	The Hypalon membrane is 45-mil reinforced CSPE (chlorosulfonated polyethylene). Reinforcement is a 10 by 10 (thread count) polyester scrim. The geotextile cushion is Polyfelt TS-1000, a 16-ounce needle-punched, nonwoven geotextile.
Prime Contractors:	Environmental Liners Inc.
Material Suppliers:	JP Stevens Elastomerics Polyfelt Inc.
Subgrade Preparation:	Extensive subgrade preparation was performed to meet the requirements of the lining supplier. The contractor removed all loose rock, dressed back the slopes, covered the entire canal cross-section with 2 inches of dirt, and raked smooth.
Construction:	The 40- by 500-foot geotextile cushion and the 35- by 500-foot hypalon liner were both prefabricated at the factory based on typical canal dimensions. The geotextile cushion was rolled out along the length of the canal, followed by the geomembrane.
Difficulties:	The 35-foot-wide geomembrane did not cover the entire canal prism and had to be solvent seamed lengthwise to a 10-foot-wide section.
Unit cost estimate:	$1.11 per square foot
Advantages:	This system is easy to install, including the solvent seams.
Disadvantages:	All exposed geomembranes are susceptible to vandalism and animal damage, limit the operation of maintenance equipment in the canal, undergo thermal expansion and contraction (to varying degrees), and are subject to uplift if not anchored in the invert. In addition, although the exposed Hypalon geomembrane can be repaired by solvent seaming, Hypalon continues to crosslink with age, and can become difficult to repair.
Photographs:	31 through 34

Arnold Canal
Test Section 5
Exposed 45-mil Hypalon (reinforced) membrane with 16-ounce geotextile cushion

Photograph 31. — Crew installs geotextile on canal bottom and side slopes.

Photograph 32. — Ten-man crew installs geomembrane.

Arnold Canal
Test Section 5
Exposed 45-mil Hypalon (reinforced) membrane with 16-ounce geotextile cushion

Photograph 33. — Two membranes are seamed using solvent seaming process.

Photograph 34. — Completed canal section.

Test Section 6. —

Material:	Exposed 36-mil Terra-Tuff geomembrane
Date installed:	March 1992
Location:	Station 35+00 to 40+00 (500 linear feet; 15,000 square feet)
Description:	JP Stevens Terra-Tuff 801R is a Hypalon/geotextile geocomposite consisting of 36-mil reinforced Hypalon laminated to an 8-ounce nonwoven PET (polyethylene terephthalate) geotextile
Prime Contractor:	Environmental Liners Inc.
Material Suppliers:	JP Stevens Elastomerics
Subgrade Preparation:	Extensive subgrade preparation was performed to meet the requirements of the lining supplier. The contractor removed all loose rock, dressed back the slopes, covered the entire canal cross-section with 2 inches of dirt, and raked smooth.
Construction:	A 35- by 500-foot Terra-Tuff panel was prefabricated at the factory based on typical canal dimensions. The Terra-Tuff panel was installed geotextile-side down to protect the membrane from the rough subgrade.
Difficulties:	The 35-foot-wide geomembrane did not cover the entire canal prism and had to be solvent seamed lengthwise to a 10-foot-wide panel.
Unit cost estimate:	$1.03 per square foot
Advantages:	This system is easy to install, including the solvent seams. The convenience of the geotextile/geomembrane composite added to the ease of installation.
Disadvantages:	All exposed geomembranes are susceptible to vandalism and animal damage, limit the operation of maintenance equipment in the canal, undergo thermal expansion and contraction (to varying degrees), and are subject to uplift if not anchored in the invert. In addition, although the exposed Hypalon geomembrane can be repaired by solvent seaming, Hypalon continues to crosslink with age, and can become difficult to repair.
Photographs:	35 through 38

Arnold Canal
Test Section 6
Exposed 36-mil Terra-Tuff geomembrane

Photograph 35. — Prefabricated Terra-Tuff panel covers two-thirds of canal prism.

Photograph 36. — Second Terra-Tuff panel in place, ready for seaming.

Arnold Canal
Test Section 6
Exposed 36-mil Terra-Tuff geomembrane

Photograph 37. — Crew joins Terra-Tuff panels using solvent seaming process.

Photograph 38. — Completed canal section.

Test Section 7. —

Material:	40-mil PVC with 3-inch grout-filled mattress
Date installed:	November 1991
Location:	Station 40+00 to 48+00 (800 linear feet; 24,000 square feet)
Description:	40-mil Oxyflex PVC membrane with Armorform 3-inch USM (Uniform Section Mat) grout-filled mattress. Cement grout was an 8-sack mix (94 lb of cement per sack) using 1,800 to 2,200 lb of sand per yd^3. Grout in downstream half of test section reinforced with 1½ lb/yd^3 polyfibers.
Prime Contractor:	Pacific Erosion Control
Material Suppliers:	Occidental Chemical Corporation Nicolon Corporation
Subgrade Preparation:	Moderate subgrade preparation consisted of removing large, loose boulders on the channel bottom and knocking down areas of scour overhang along the bank.
Construction:	A five-man crew spread the PVC liner panels and pulled them into the canal bottom. The prefabricated, 23- by 70-foot PVC panels covered the entire canal bottom and extended part way up the side slopes. The crew, proceeding upstream, overlapped each upstream panel about 2 feet over the downstream panel. After the PVC panels were placed, the lap joints were solvent seamed. To accommodate channel width variations, Armorform panels were factory fabricated in 29-foot, 30-foot, and 35-foot widths. Panel dimensions were based upon representative cross-section sketches provided by Reclamation, plus an allowance for fabric contraction during pumping. Beginning at the downstream end, the crew unrolled the Armorform panels and positioned them loosely along the canal bottom, with the fabric extending up the side slopes and over the top of the bank. Adjacent panels were joined together with factory installed zippers. The Armorform fabric was secured along the top of the bank with ropes tied off to rebar stakes. Beginning again at the downstream end, the crew grouted the Armorform panels. A slit was cut with scissors in the top layer of the Armorform fabric, the grout nozzle inserted, and grout was pumped into the mat. Pumping continued until either the grout stopped flowing or the fabric surrounding the injection point became stressed. Then the grout nozzle was withdrawn and the nozzle was moved to the next injection point. The hole was troweled smooth after grout in the mat stiffened. Where an underlying rock created a significant protrusion, the grout in the mat was worked around the obstruction to facilitate flow.

Extended periods of below-freezing temperatures were forecast; therefore, insulation blankets were installed over the last 600 feet of grouted canal lining to protect the mat from freezing.

Difficulties: The grouting operation needs a uniform delivery of grout mix. At one point, the pump labored with an unusually stiff grout batch, causing a lock pin to vibrate out and a temporary delay for pump repair.

The first loads of concrete delivered were a sand/cement mixture. However, later loads included Forta CFP, polypropylene fiber reinforcement, at the rate of 1.5 lbs/yd^3. Unfortunately, the fibrillated fiber bundles caught on the pump hopper screen, requiring repeated cleaning of the screen. The fibers were also suspected of hanging up on the cross-ties within the grout mattress, adding to grout flow difficulties. Switching to monofilament reinforcement (Forta Mono Fiber) eliminated the blockage problem.

Unit cost estimate: $2.36 per square foot.

Advantages: The grout mattress is aesthetically pleasing, works well over irregular subgrades, eliminates the need for an anchor trench, and assures uniform 3-in concrete thickness. The crew was able to continue working through periods of heavy rain. This test section included areas that had not yet drained and which were pumped under water. The PVC geomembrane under the grout mattress provides positive seepage control.

Disadvantages: The geotextile facing on the grout blanket will wear away in a few years, exposing the concrete "pillows." Stability of the concrete pillows without the geotextile facing is unknown.

Photographs: 39 through 48

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

Photograph 39. — Completed canal subgrade after removal of overhang on canal side slope. Note standing water in canal.

Photograph 40. — 40-mil PVC membrane in place, ready for grout mattress.

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

Photograph 41. — Worker places grout mattress cover in canal bottom over PVC geomembrane.

Photograph 42. — Mattress in place, ready for seaming (zipper).

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

Photograph 43. — The mattress panels, sized to the canal in the factory, are zipped together (seamed).

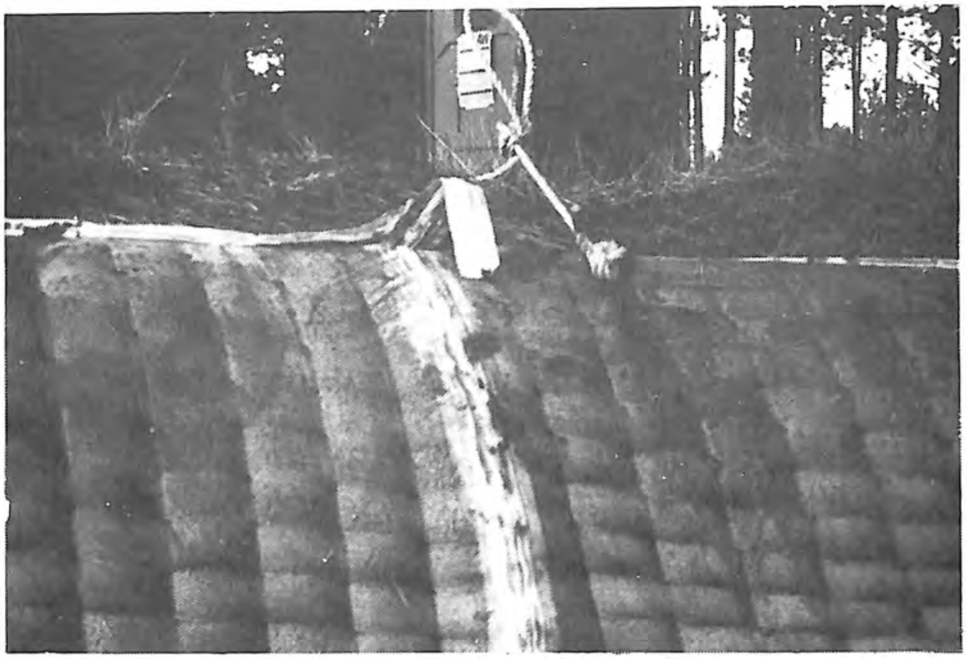
Photograph 44. — Grout mattress in place and ready for grouting. Note ties on right side used to hold grout mattress in place.

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

Photograph 45. — Grout mix is transferred to grout pump.

Photograph 46. — A five-man crew works the grout mix through the mattress.

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



Photograph 47. — Grout mix flows through the zipper into the next panel.

Photograph 48. — Completed canal section.

Test Section 8. —

Material:	3-inch grout-filled mattress
Installation date:	November 1991 (200-foot section) November 1992 (500-foot section)
Location:	Station 48+00 to 55+00 (700 linear feet; 21,000 square feet) Station 48+00 to 50+00 (November 1991) Station 50+00 to 55+00 (November 1992)
Description:	The grout-filled mattress is Armorform 3-inch USM (Uniform Section Mat). Some of the Armorform panels are made of polypropylene fibers (yellow-brown), and the remainder are made of polyester fibers (white). Cement grout was an 8-sack mix (94 lb of cement per sack) using 1,800 to 2,200 lb of sand per yd^3.
Prime Contractor:	Pacific Erosion Control (November 1991) Canamer International Inc. (November 1992)
Material Supplier:	Nicolon Corporation
Subgrade Preparation:	Minimal subgrade preparation consisted of removing numerous large, loose boulders in the channel bottom and knocking down scour overhang areas along the bank.
Construction:	700 linear feet of Armorform 3-inch USM fabric was placed directly over the subgrade and side slopes. The first 200 feet (up to the bridge) were placed at the same time test section 7 lining was installed, including prefabricated panels and zipper seams. The Armorform panels were cut and sewn to fit snugly around the maintenance bridge using a generator-powered portable sewing machine. For the next 500-foot section, scheduling did not permit time for shop fabrication of the Armorform fabric into prefabricated panels. Therefore, the bulk fabric was delivered to the site, where it was field-tailored by a four-man crew. The crew first unrolled the USM fabric on the ground. The fabric was then cut into lengths to fit the cross-section of the canal and then sewn into panels using a generator-powered sewing machine. The panels were pulled into the canal, spread out loosely, and then stitched together to create a continuous section. The Armorform was lapped 2 feet over the upstream lining installed the previous year. When the fabric was positioned to cover the side slopes, it was secured with ropes and rebar stakes to prevent the fabric from slipping during the grouting process. Panels contract as they are filled with grout; therefore, the fabric manufacturers recommend a 4-percent contraction allowance in each direction. The grout was pumped into

Required equipment included concrete trucks, one grout pump, 220 feet of 2-inch hose, two portable sewing machines, and a generator. A five-man crew (a pump operator and four laborers) installed this section.

Difficulties: The first truckload of grout was returned to the plant because the mix was too stiff to flow. It was later discovered that the first batch had too much sand in the grout mix (2,700 lb/yd^3). Once the proper mix was delivered (1,800 lb/yd^3), it was pumped with expected efficiency. Random loads with inconsistent aggregate grading were also rejected. The importance of the correct grout mix cannot be overemphasized in grout mattress work.

Unit cost estimate: $1.86 per square foot

Advantages: The grout mattress is aesthetically pleasing, works well over irregular subgrades, eliminates the need for an anchor trench, and assures uniform 3-in concrete thickness.

Disadvantages: This test section relies solely on the grout mattress for seepage control. The geotextile facing on the grout blanket will wear away in a few years and exposing the concrete "pillows." Stability of the concrete pillows without the geotextile facing is unknown.

Photographs: 49 through 52

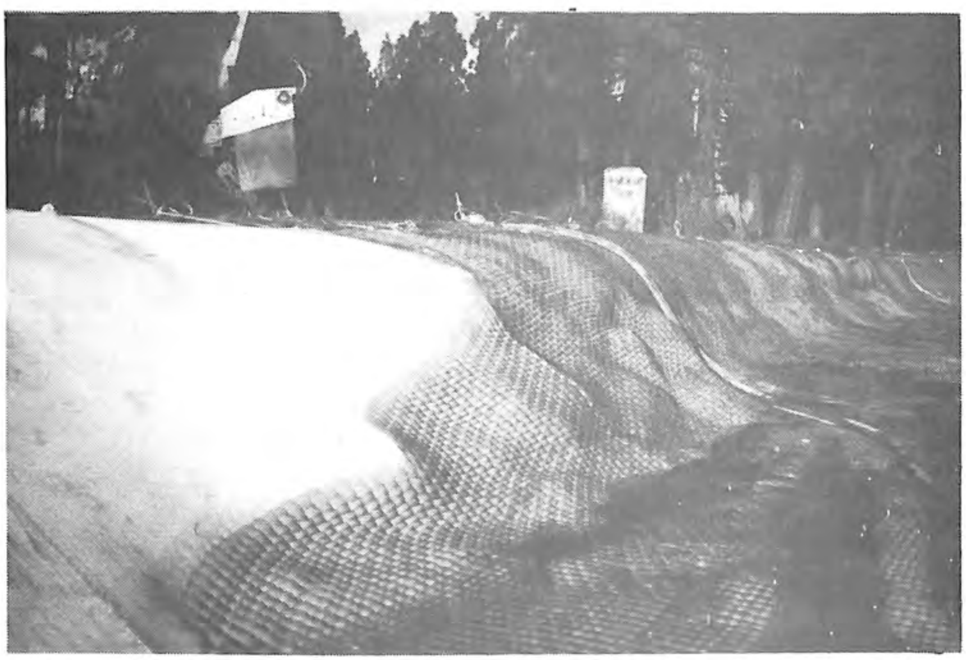
Arnold Canal
Test Section 8
3-inch grout-filled mattress

Photograph 49. — After only minimal subgrade preparation, the mattress is laid directly over the rocky side slopes.

Photograph 50. — Final preparation work before grout is pumped into mattress.

Arnold Canal
Test Section 8
3-inch grout-filled mattress

Photograph 51. — Grout is worked around a bridge abutment.



Photograph 52. — Mattress conforms to irregular subgrade.

Test Section 9. —

Material:	60-mil VLDPE with 12-ounce geotextile cushion and 3-inch grout-filled mattress on side slopes only
Date installed:	November 1992
Location:	Station 55+00 to 65+00 (1,000 linear feet; 30,000 square feet)
Description:	The VLDPE is 60-mil, Poly-America Dura-flex. The geotextile cushion is Amoco 4512 (12-ounce needle-punched, nonwoven geotextile). About 6 feet of each side slope was covered with Nicolon Armorform 3-inch USM grout-filled mattress. The VLDPE geomembrane in the canal bottom was left exposed.
Prime Contractor:	Canamer International Inc.
Material Suppliers:	Nicolon Corporation Poly-Flex Inc. Amoco Fabrics and Fibers Co.
Subgrade Preparation:	Moderate subgrade preparation consisted of removing large, loose boulders in the channel bottom and knocking down scour overhang areas along the bank. Sedimented areas were scraped out and used as fill in rocky areas on side slopes and in the canal bottom. The Arnold Irrigation District also requested some additional subgrade work to remove rock outcrop areas that constricted canal flow. These areas were removed using a hydraulic jackhammer mounted on a backhoe.
Construction:	Two rolls of geotextile were placed in the channel lengthwise and positioned to cover as much of the canal bottom and side slopes as possible. Geomembrane and geotextile scraps were used as additional cushion over rock outcroppings. The geomembrane was rolled across the canal prism with hot-wedge welded seams perpendicular to the channel. An extrusion welder was used for minor repairs. This test section attempted to minimize the amount of required earth work. An anchor trench was not used. Instead, the Armorform grout mattress was used to anchor the side slopes and the top of the berm area. The Armorform grout mattress was unrolled lengthwise along each side slope and the VLDPE geomembrane was left exposed in the canal bottom.
Difficulties:	Frost on the membrane created slippery, dangerous conditions. Frost also caused delays in seaming because the installers had to wait for warmer conditions.
Unit cost estimate:	$1.79 per square foot

Because the geomembrane in the canal bottom is left exposed, the cost for this lining technology ranges from $1.49 to $2.64 per square foot, depending on the geometry of the canal prism (table 4).

Advantages: The grout mattress is aesthetically pleasing, works well over irregular subgrade, eliminates the need for an anchor trench, and assures uniform 3-in concrete thickness. The VLDPE is more flexible and easier to work with than HDPE.

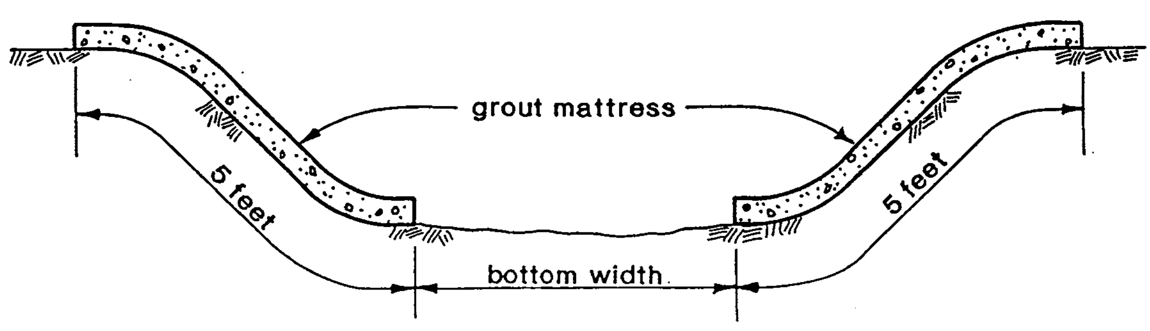
Disadvantages: The geotextile facing on the grout blanket will wear away in a few years, exposing the concrete "pillows." Stability of the concrete pillows without the geotextile facing is unknown. The exposed VLDPE geomembrane in the invert is susceptible to vandalism and animal damage, limits the operation of maintenance equipment in the canal, will undergo thermal expansion and contraction (more pronounced for VLDPE than HDPE), and is subject to uplift because it is not anchored in the invert. Finally, repair of the exposed VLDPE requires purchase of an extrusion welder (about $7,000 new).

Photographs: 53 through 62

Table 4. — Costs for installing 60-mil VLDPE or HDPE with 3-inch grout-filled mattress on side slopes only (100,000 square feet).

Lined perimeter width (feet)	Grout mattress: grout & mattress ($1.10/ft^2)	60-mil geomembrane ($0.55/ft^2)*	12-ounce geotextile ($0.12/ft^2)	Installation cost per ft^2 (lump sum)	Overhead and profit (17%)	Total cost per ft^2
10	$110,000	$55,000	$12,000	$49,000	$264,420	$2.64
15	$73,337	$55,000	$12,000	$49,000	$221,524	$2.22
20	$55,000	$55,000	$12,000	$49,000	$200,070	$2.00
30	$36,663	$55,000	$12,000	$49,000	$178,616	$1.79
40	$27,500	$55,000	$12,000	$49,000	$167,895	$1.68
60	$18,337	$55,000	$12,000	$49,000	$157,174	$1.57
80	$13,750	$55,000	$12,000	$49,000	$151,808	$1.52
100	$11,000	$55,000	$12,000	$49,000	$148,590	$1.49

* HDPE costs about $0.02/ft^2 less than VLDPE
Canal size:
Canal length varies = 100,000 ft^2/perimeter
Grout mattress side slope = 5 feet each side, 10 feet total
Lined perimeter = bottom width + 10 feet



Arnold Canal
Test Sections 9 and 10
Exposed 60-mil VLDPE (9) and 60-mil HDPE (10)
with 3-inch grout-filled mattress on side slopes only

Photograph 53. — Geotextile cushion is laid out along road, ready to be placed in canal.

Photograph 54. — Geotextile is placed in canal to centerline.
A second geotextile cushion will cover other half of the canal.

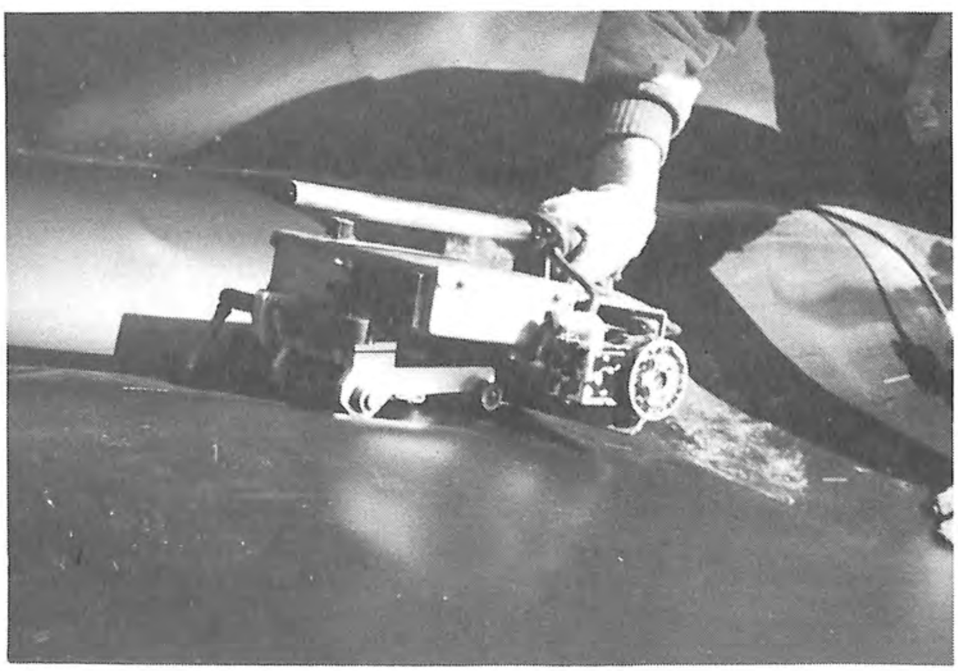
Arnold Canal
Test Sections 9 & 10
Exposed 60-mil VLDPE (9) and 60-mil HDPE (10) with 3-inch grout-filled mattress on side slopes only

Photograph 55. — Completed geotextile cushion installation.

Photograph 56. — Geomembrane is rolled out and cut to fit canal prism.

Arnold Canal
Test Sections 9 & 10
Exposed 60-mil VLDPE (9) & 60-mil HDPE (10) with 3-inch grout-filled mattress on side slopes only

Photograph 57. — Membrane material is rolled across canal and up side slopes.



Photograph 58. — Membrane is seamed with hot wedge welder.

Arnold Canal
Test Sections 9 & 10
Exposed 60-mil VLDPE (9) & 60-mil HDPE (10)
with 3-inch grout-filled mattress on side slopes only

Photograph 59. — Grout mattress is placed in canal.

Photograph 60. — Mattress is pulled into place on side slopes.
Geomembrane in canal bottom is left exposed.

Arnold Canal
Test Sections 9 & 10
Exposed 60-mil VLDPE (9) & 60-mil HDPE (10)
with 3-inch grout-filled mattress on side slopes only

Photograph 61. — Grout is pumped into mattress.

Photograph 62. — Completed canal section. Standing water covers exposed geomembrane.

Test Section 10. —

Material:	60-mil HDPE with 12-ounce geotextile cushion and 3-inch grout-filled mattress on side slopes only
Installation date:	November 1992
Location:	Station 65+00 to 75+00 (1,000 linear feet; 30,000 square feet)
Description:	The HDPE is 60-mil Poly-Flex. The geotextile cushion is Amoco 4512 (12-ounce needle-punched, nonwoven geotextile). About 6 feet of each side slope was covered with Armorform 3-inch, USM grout-filled mattress. The HDPE geomembrane in the canal bottom was left exposed.
Prime Contractor:	Canamer International Inc.
Material Suppliers:	Nicolon Corporation Poly-Flex Inc. Amoco Fabrics and Fibers Co.
Subgrade Preparation:	Same as test section 9.
Construction:	Same as test section 9, except the geomembrane is 60-mil HDPE.
Difficulties:	Frost on the membrane created slippery, dangerous conditions. Frost also caused delays in seaming because installers had to wait for dryer, warmer conditions to seam the material. Rain and snow added to the slippery footing and caused puddling in the canal bottom.
Unit cost estimate:	$1.79 per square foot Because the geomembrane in the canal bottom is left exposed, the cost for this lining technology ranges from $1.49 to $2.64 per square foot, depending on the geometry of the canal prism (table 4).
Advantages:	The grout mat is aesthetically pleasing, works well over irregular subgrades, eliminates the need for an anchor trench, and assures uniform 3-in concrete thickness. The exposed HDPE is inert to many chemicals and offers excellent weatherability. HDPE also undergoes less thermal expansion and contraction than VLDPE. Finally, HDPE is slightly less expensive than VLDPE (about $\$0.02/ft^2$ less expensive).
Disadvantages:	The geotextile facing on the grout blanket will wear away in a few years, exposing the concrete "pillows." Stability of the concrete pillows without the geotextile facing is unknown. The exposed HDPE geomembrane in the invert is susceptible to vandalism and animal damage, limits the operation of maintenance equipment in the canal, will undergo thermal expansion and contraction, and is subject to uplift because it is not anchored in the invert. Finally, repair of the exposed HDPE requires purchase of an extrusion welder (about $7,000 new).
Photographs:	53 through 62

North Unit Main Canal

The North Unit Irrigation District is located east of the Deschutes River and north of the Crooked River in central Oregon. The district supplies water to about 59,000 acres of farmland. Project construction began in 1938, and the project was operated by Reclamation until 1955, when the North Unit Irrigation District assumed operation. Main project features include Wickiup Reservoir (200,000 acre-feet of storage), Haystack Reservoir (6,600 acre-feet of storage), Crooked River Pumping Plant, 65 miles of main canal, and 235 miles of laterals.

District water from Wickiup Reservoir (located on the Deschutes River) is diverted from the Deschutes River at Bend, Oregon, into the North Unit Main Canal. The North Unit Main Canal averages about 60 feet wide and 10 feet deep. Capacity is about 1,100 ft^3/s at the diversion.

Eight test sections were constructed on the North Unit Canal. Lining technologies included spray-applied foam, coated fabrics, and shotcrete. A ninth test section using soil-cement was cancelled when the contractor could not perfect his technology for field application. Appendix D contains the manufacturers' data sheets for the linings installed on the North Unit Main Canal.

Test Section 1. —

Material:	SPUF (spray-applied polyurethane foam) base with Futura 500/550 protective coating
Date installed:	October 1992 and March 1993
Location:	Station -02+00 to 01+00 (300 linear feet; 18,000 square feet)
Description:	SPUF is a minimum of 2 inches of 2-pound (lb/ft^3) foam covered with about ½ inch of 5-pound foam. Protective coatings are a base coat of Futura 500 (aromatic urethane) and a topcoat of UV-resistant Futura 550 (aliphatic urethane). Total coating thickness is 50-55 mils.
Prime Contractor:	Holton Enterprises Inc.
Material Suppliers:	Montana Urethane Systems Supply Futura Coatings Inc.
Subgrade Preparation:	Minimal subgrade preparation involved removal of debris and large loose rocks within the canal prism, providing a clean, even surface for the foam to bond.
Construction:	After canal cleaning, a 2-pound foam was spray-applied to fill voids and smooth out the subgrade (nominally 2 inches thick). Then, about ½ inch of 5-pound foam was sprayed over the 2-pound foam to provide a hard surface. Inclement weather delayed application of the Futura 500/550 protective coating until spring (about 5 months). The Futura 500 basecoat is tan in color, and the Futura 550 topcoat is white.
Difficulties:	Because the canals are in use during prime construction season (April - August), construction must be completed during the winter months or during very short construction windows in late fall or early spring. This schedule creates a problem because the SPUF is manufactured on-site and is extremely susceptible to adverse weather. Rain and cold temperatures in the fall made construction difficult and forced postponement of completion until spring. Both the 2- and 5-pound foams were applied in the fall, but were left unprotected throughout the winter. Protective coatings were not applied until spring. Therefore, the bond between the foam and coatings is suspect. The irregular subgrade resulted in a less-than-smooth foam surface. Applying uniform layers of protective coating was difficult, and more coating was required to achieve the desired minimum coating thickness.
Unit cost estimate:	\$4.33 per square foot
Advantages:	Foam can be applied over very irregular surfaces, and expands to seal cracks and voids. Foam will bond to almost any surface, creating a seamless membrane.

Disadvantages:	SPUF is essentially manufactured on-site, and quality is susceptible to adverse weather conditions such as rain, fog, snow, low temperatures, wind, etc. The slow-set Futura 500/550 coatings must cure overnight before reapplication. This SPUF liner is essentially an exposed membrane and is susceptible to abrasion, vandalism, and animal damage, and limits operation of maintenance equipment in the canal.
Photographs:	63 through 70

North Unit Main Canal
Test Section 1
Spray-applied polyurethane foam base with Futura 500/550 protective coatings

Photograph 63. — Two-pound density foam is applied directly to subgrade.

Photograph 64. — Completed application of 2-pound density foam.

North Unit Main Canal
Test Section 1
Spray-applied polyurethane foam base
with Futura 500/550 protective coatings

Photograph 65. — Spray gun used to apply foam.

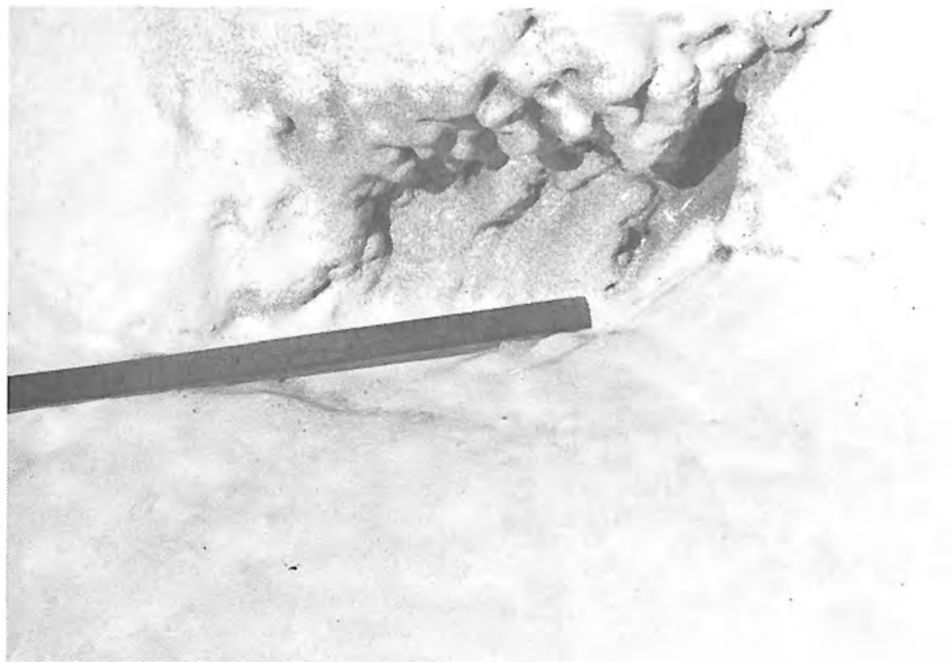
Photograph 66. — Foam bonds well to all surfaces, including this bridge abutment.

North Unit Main Canal
Test Section 1
Spray-applied polyurethane foam base with Futura 500/550 protective coatings

Photograph 67. — The lighter colored five-pound foam is applied over the darker 2-pound foam.

Photograph 68. — Dark area on left is 2-pound foam beneath newly applied 5-pound foam, on right.

North Unit Main Canal
Test Section 1
Spray-applied polyurethane foam base with Futura 500/550 protective coatings



Photograph 69. — White 550 topcoat over tan 500 base coat. Irregular foam surface made 100% coverage difficult to obtain.

Photograph 70. — Completed canal section.

Test Section 2. —

Material:	SPUF (spray-applied polyurethane foam) base with Geothane 5020 protective coating
Date installed:	October 1992
Location:	Station 01+00 to 04+00 (300 linear feet; 18,000 square feet).
Description:	SPUF is a minimum of 2 inches of 2-pound foam covered with about ½ inch of 5-pound foam. Protective coating is Geothane 5020 (a two-part, 100% solid, hydrocarbon-modified urethane). Coating thickness averaged 50-60 mils.
Prime Contractor:	Holton Enterprises Inc.
Material Suppliers:	Montana Urethane Systems Supply Futura Coatings Inc.
Subgrade Preparation:	Minimal subgrade preparation involved removal of debris and large loose rocks within the canal prism, providing a clean, even surface for the foam to bond.
Construction:	After the canal was cleaned, a 2-pound foam was spray-applied to fill voids and smooth out the subgrade (nominally 2 inches thick). Then, about ½ inch of 5-pound foam was sprayed over the 2-pound foam to provide a hard surface. The Geothane 5020 was applied in a single, thick coat.
Difficulties:	Because the canals are in use during prime construction season (April - August), construction must be completed during the winter months or during very short construction windows in late fall or early spring. This schedule creates a problem because the SPUF is essentially manufactured on-site and is extremely susceptible to adverse weather. Rain and cold temperatures made construction difficult.
Unit cost estimate:	$3.92 per square foot
Advantages:	Foam can be applied over very irregular surfaces with minimal subgrade preparation. The SPUF expands to fill and seal cracks and voids, and will bond to almost any surface, creating a seamless membrane. The fast-set Geothane 5020 proved more convenient than the slow-set Futura 500/550.
Disadvantages:	SPUF is essentially manufactured on-site, and quality is susceptible to adverse weather conditions such as rain, fog, snow, low temperatures, wind, etc. This SPUF liner is essentially an exposed membrane and is susceptible to abrasion, vandalism, and animal damage, and limits operation of maintenance equipment in the canal.
Photographs:	71 and 72

North Unit Main Canal
Test Section 2
Sprayed-applied polyurethane foam base
with Geothane 5020 protective coating

Photograph 71. — Black Geothane 5020 applied at left;
white Futura 500/550 applied at right.

Photograph 72. — Completed canal section.

Test Section 3. —

Material:	Tietex geotextile with spray-applied Geothane 5020 membrane
Date installed:	October 1992
Location:	Station 04+00 to 07+00 (300 linear feet; 18,000 square feet)
Description:	Tietex is a 6-ounce woven geotextile, which is spray-coated in the field with 60 mils of fast-setting Futura Geothane 5020. The Futura 5020 is a two-component, 100% solids, hydrocarbon-modified urethane coating that completely cures in about 60 seconds. The Geothane 5020 fully saturates the geotextile to form a watertight membrane.
Prime Contractor:	Holton Enterprises Inc.
Material Suppliers:	Montana Urethane Systems Supply Futura Coatings Inc. Tietex Corporation
Subgrade Preparation:	Minimal subgrade preparation included removing loose debris (foreign material, weeds, trees) and larger, loose rock (4 inches and larger). A small quantity of pit-run sand was spread over the floor of the canal to fill voids.
Construction:	The 4-foot-wide geotextile was rolled out along the length of the canal. Five-pound SPUF was used to anchor the geotextile along the top of the rocky side slopes. Futura Geothane 5020 was then spray-applied to the geotextile to a thickness of 60 mils. A freshly wetted 3-inch overlap was used to attach the next 4-foot width of geotextile. After the seam cured for 60 seconds, Futura 5020 was applied to the fresh geotextile. This process continued until the entire canal was lined. Geothane 5020 was applied at elevated temperatures (300 to 400 °F).
Difficulties:	Hot-applied spray coating is susceptible to cold temperatures; many of the splices between geotextile rolls were of marginal quality. Also, although Geothane 5020 did saturate the geotextile, essentially no bond was established between the liner and the rocky subgrade. Finally, the side slopes were extremely rocky and the liner had to span the gaps between rocks. A smooth side slope is preferable for this type of lining.
Unit cost estimate:	$2.64 per square foot
Advantages:	This lining system is relatively simple to install, and the rapid-set coating allowed rapid construction.
Disadvantages:	This exposed membrane liner is susceptible to abrasion, vandalism, and animal damage; limits the operation of maintenance equipment in the canal; will undergo thermal expansion and contraction, and is subject to uplift because it is not anchored in the invert.
Photographs:	73 through 80

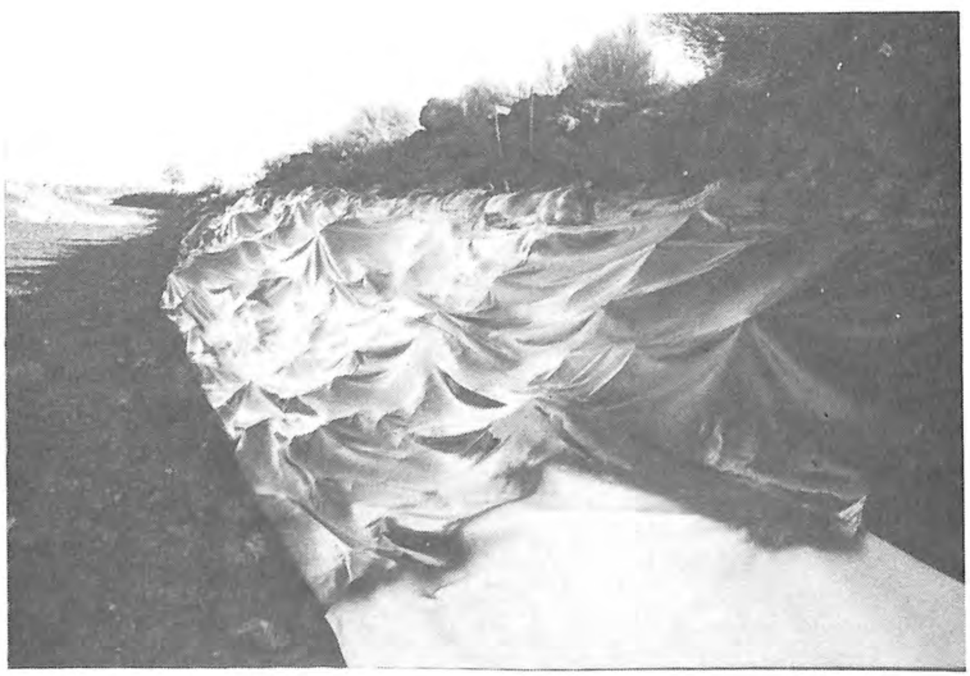
North Unit Main Canal
Test Section 3
Tietex geotextile with spray-applied Geothane 5020

Photograph 73. — The 4-foot-wide geotextile is anchored above the water line.

Photograph 74. — Coating is spray-applied over geotextile.

North Unit Main Canal
Test Section 3
Tietex geotextile with spray-applied Geothane 5020

Photograph 75. — Second roll of textile is placed into fresh coating.



Photograph 76. — Overlap seam between first and second roll.

North Unit Main Canal
Test Section 3
Tietex geotextile with spray-applied Geothane 5020

Photograph 77. — Geotextile is rolled into place.

Photograph 78. — Coating is applied to geotextile.

North Unit Main Canal
Test Section 3
Tietex geotextile with spray-applied Geothane 5020

Photograph 79. — View of the side slope and the geotextile anchored with spray-in-place foam.

Photograph 80. — Completed canal section.

Test Section 4. —

Material:	Phillips geotextile with spray-applied Geothane 5020 membrane
Date installed:	October 1992
Location:	Station 07+00 to 10+00 (300 linear feet; 18,000 square feet)
Description:	Liner is a 6-ounce needle-punched nonwoven geotextile (Phillips Roof-On E-6N), spray-coated in the field with 60 mils of fast-setting Futura Geothane 5020.
Prime Contractor:	Holton Enterprises Inc.
Material Suppliers:	Montana Urethane Systems Supply Futura Coatings Inc. Tietex Corporation
Subgrade Preparation:	Minimal subgrade preparation included removing loose debris (foreign material, weeds, trees) and larger, loose rock (4 inches and larger). A small amount of pit-run sand was spread over the floor of the canal to fill voids.
Construction:	The 4-foot-wide geotextile was rolled out along the length of the canal. Five-pound SPUF was used to anchor the geotextile along the top of the rocky side slopes. Futura Geothane 5020 was then spray-applied to the geotextile to a thickness of 60 mils. The Futura 5020 is a two-component coating that completely cures in about 60 seconds. A freshly wetted 3-inch overlap was used to attach the next 4-foot width of geotextile. After the seam cured for 60 seconds, Futura 5020 was applied to the fresh geotextile. This process continued until the entire canal was lined. Geothane 5020 was applied at elevated temperatures (300 to 400 °F).
Difficulties:	Hot-applied spray coating is susceptible to cold temperatures. Also, the Geothane 5020 did not saturate the geotextile, and no bond existed between the liner and the rocky subgrade. Finally, the side slopes were extremely rocky and the liner had to span the gaps between rocks. A smooth side slope is preferable for this type of lining.
Unit cost estimate:	$2.64 per square foot
Advantages:	This lining system is relatively simple to install, and the rapid-set coating allowed rapid construction.
Disadvantages:	This exposed membrane liner is susceptible to abrasion, vandalism, and animal damage; limits the operation of maintenance equipment in the canal; will undergo thermal expansion and contraction; and is subject to uplift because it is not anchored in the invert.
Photographs:	81 through 82

North Unit Main Canal
Test Section 4
Phillips Geotextile with sprayed-applied Geothane 5020

Photograph 81. — Completed canal section.

Photograph 82. — Completed canal sections (900 feet) with the Geothane 5020 coating.

***Test Section 5.* —**

Material:	No contract awarded. This section was originally intended for a soil-cement lining. However, the contractor was unable to deliver workable technology, and no contract was executed.
Location:	Station 10+00 to 20+00 (1,000 linear feet; 60,000 square feet)

Test Section 6. —

Material:	3-inch shotcrete reinforced with Novacon steel fibers
Date installed:	February 1992
Location:	Station 20+00 to 25+00 (500 linear feet; 30,000 square feet)
Description:	Steel fibers are 1½-inch Novocon crimped fibers (Novocrimp). Shotcrete work was performed in accordance with ACI (American Concrete Institute) 506.2 Specification for Materials, Proportioning, and Application of Shotcrete. Shotcrete cover was applied by the wet-mix process using 7-sack pea-gravel pump mix (94 lb of cement per sack, ⅜-in maximum aggregate size).
Prime Contractor:	Johnson Western Gunite Co.
Material Supplier:	Novocon International Corporation
Subgrade Preparation:	Only minimal subgrade preparation was performed. The irrigation district removed large boulders (6 inches and larger) from the canal bottom, but little else was done before the shotcrete lining was applied. On the left bank, the contractor attempted to fill voids on the irregular side slopes with sand and gravel material to reduce the amount of shotcrete required. However, this work was abandoned because the imported fill material was a silty soil unsuitable for subgrade. The material "bridged over" rather than filled voids and quickly washed out of place.
Construction:	The first 250 feet of shotcrete contained 50 lb/yd^3 of steel fiber; the second 250 feet contained 25 lb/yd^3. The fibers did not alter the pumping characteristics of the shotcrete mix at either dosage. The shotcrete was left with a rough "as shot" or nozzle finish. The shotcrete was sprayed with curing compound and, as needed, covered with tarps for 3 days to prevent freezing.
Difficulties:	Installers had difficulty applying a uniform 3-inch layer of shotcrete over the irregular surface, even though one worker constantly checked shotcrete thickness. The irregular shotcrete thickness is not in itself detrimental; however, it increases the chance for thin spots that will need repair in the future.
Unit cost estimate:	\$1.59 at a fiber dosage of 50 lb/yd^3; \$1.44 at a fiber dosage of 25 lbs/yd^3
Advantages:	Shotcrete can be applied over very irregular subgrade with little or no subgrade preparation. Shotcrete provides a hard wearing surface that is not susceptible to vandalism or animal damage, and allows the operation of maintenance equipment in the canal prism.
Disadvantages:	Seepage is expected to increase over the years as the shotcrete ages and cracks.
Photographs:	83 through 94 (general application) and 95 through 98 (test section 6)

North Unit Main Canal
Test Sections 6, 7, 8, & 9
General application of 3-inch shotcrete

Photograph 83. — Fill material was used to fill in large voids on side slopes.
This procedure was soon discontinued because available fill material proved unsuitable.

Photograph 84. — Shotcrete crew lays out hoses.

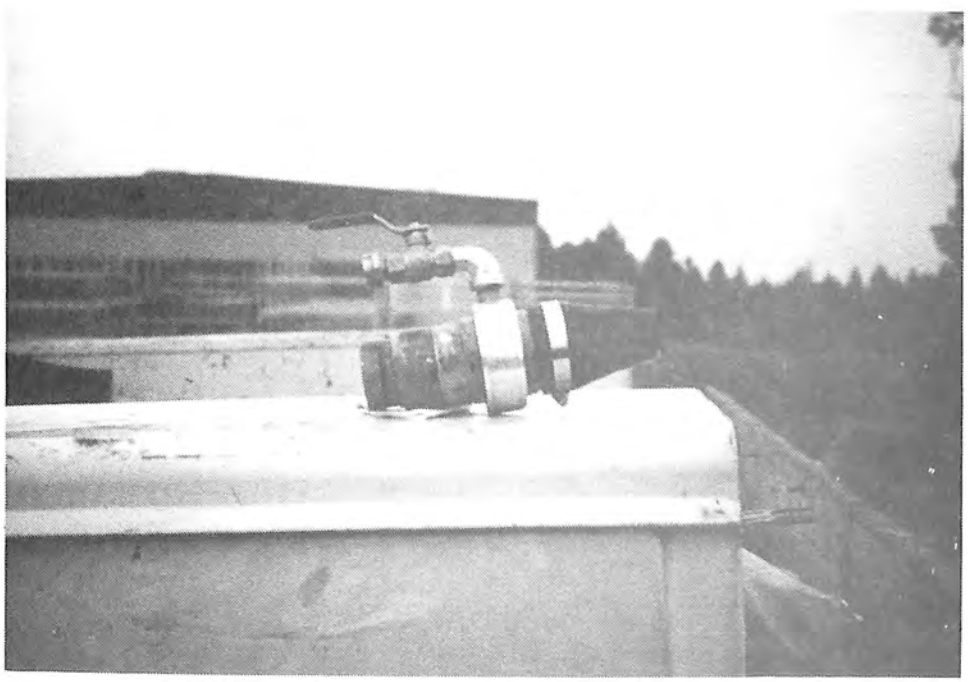
North Unit Main Canal
Test Sections 6, 7, 8, & 9
General application of 3-inch shotcrete

Photograph 85. — Fibers were added to the grout mix at the plant.

Photograph 86. — Concrete truck, grout pump, and air compressor are used for the shotcrete application.

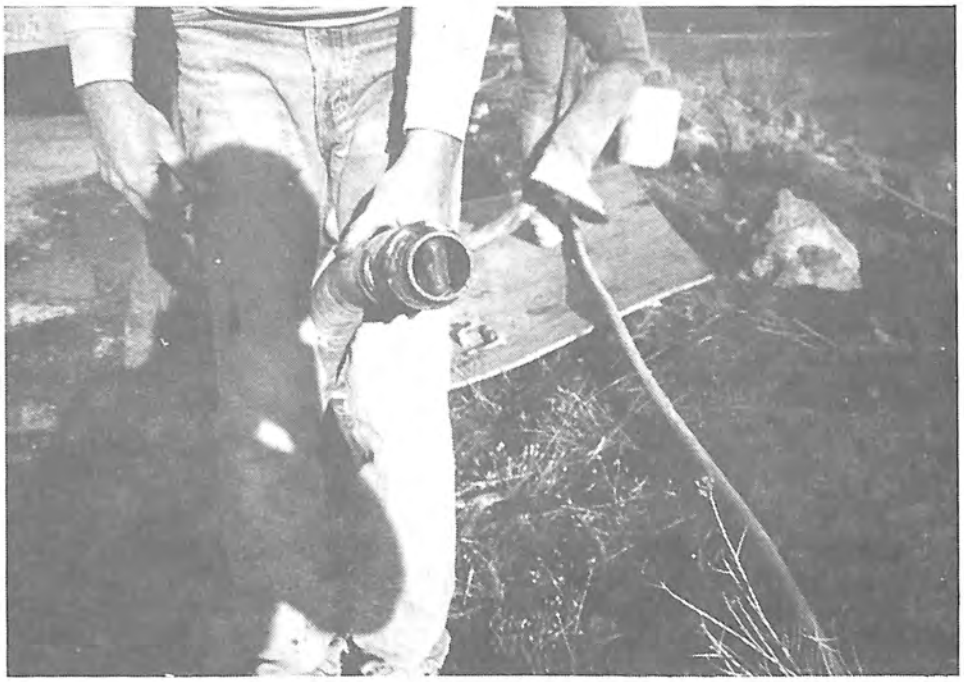
North Unit Main Canal
Test Sections 6, 7, 8, & 9
General application of 3-inch shotcrete

Photograph 87. — Grout pump.



Photograph 88. — Spray nozzle is used to apply shotcrete.
Small pipe on top provides air supply.

North Unit Main Canal
Test Sections 6, 7, 8, & 9
General application of 3-inch shotcrete



Photograph 89. — Shotcrete mix was specified as ½ inch minus aggregate. However, note 2½-inch rock wedged in the 2-inch hose.

Photograph 90. — Shotcrete application.

North Unit Main Canal
Test Sections 6, 7, 8, & 9
General application of 3-inch shotcrete

Photograph 91. — Nozzle man starts at top of canal and works his way to the bottom.

Photograph 92. — Close-up of grout being forced into voids.

North Unit Main Canal
Test Sections 6, 7, 8, & 9
General application of 3-inch shotcrete

Photograph 93. — Contractor attempted to smooth out rough finish.
This procedure was abandoned and shotcrete was left with "as shot" finish.

Photograph 94. — Curing compound applied to fresh shotcrete.

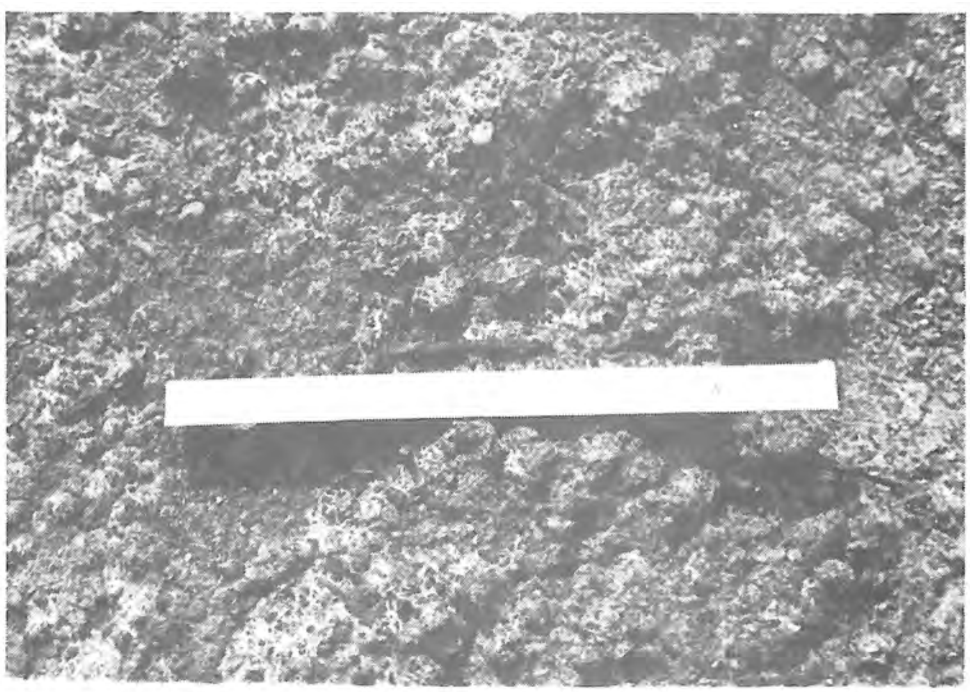
North Unit Main Canal
Test Section 6
3-inch shotcrete with steel fibers (50 and 25 lb/yd^3)

STEEL FIBER REINFORCEMENT

BY

NOVOCON INTERNATIONAL INC.

Photograph 95. — Novocon International Corp. furnished steel fibers.



Photograph 96. — 1½-inch steel fibers embedded in shotcrete.

North Unit Main Canal
Test Section 6
3-inch shotcrete with steel fibers (50 and 25 lb/yd^3)

Photograph 97. — Contractor marked location of different fiber material sections in shotcrete.

Photograph 98. — Completed canal section.

Test Section 7. —

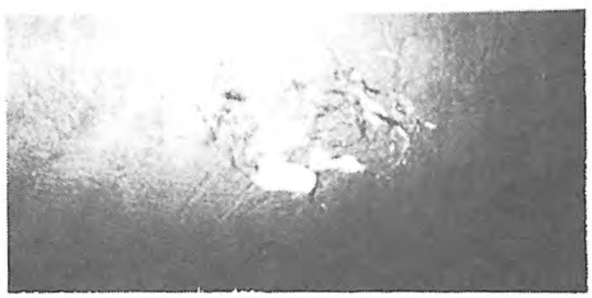
Material:	3-inch shotcrete reinforced with Phillips polyfibers
Date installed:	February 1992
Location:	Station 25+00 to 30+00 (500 linear feet; 30,000 square feet)
Description:	The polyfiber reinforcement is ¾-inch Phillips Fi-Con polypropylene fibers. Shotcrete work was performed in accordance with ACI 506.2 Specification for Materials, Proportioning, and Application of Shotcrete. Shotcrete cover was applied by the wet-mix process using 7-sack pea-gravel pump mix (94 lb of cement per sack, ⅜-in maximum aggregate size).
Prime Contractor:	Johnson Western Gunite Co.
Material Supplier:	Phillips Fibers Corporation
Subgrade Preparation:	Minimal subgrade preparation. The irrigation district removed large boulders (≥6 inches) from the canal bottom, but little else was done prior to applying the shotcrete lining.
Construction:	The first 250 feet of shotcrete contained 3 lb/yd^3 of fiber; the second 250 feet contained and 1½ lb/yd^3. The shotcrete was left with an "as shot" or nozzle finish. The shotcrete was sprayed with curing compound and, as needed, covered with light tarps for 3 days to prevent freezing.
Difficulties:	Installers had difficulty applying a uniform 3-inch layer of shotcrete. With 3 lb/yd^3 fiber, the shotcrete was difficult to pump because the fibers tended to block the hose. The irregular shotcrete thickness is not in itself detrimental; however, it increases the chance for thin spots that will need repair in the future.
Unit cost estimate:	\$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
Advantages:	Shotcrete can be applied over very irregular subgrade with little or no subgrade preparation. The polyfibers may decrease the amount of visible shotcrete cracking and improve durability. Shotcrete provides a hard wearing surface that is not susceptible to vandalism or animal damage, and allows the operation of maintenance equipment in the canal prism.
Disadvantages:	Seepage is expected to increase over the years as the shotcrete ages and cracks.
Photographs:	83 through 94 (general application) and 99 through 100 (test section 7)

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

POLYPROPYLENE FIBER REINFORCEMENT

BY

PHILLIPS FIBER CORPORATION



Photograph 99. — Polyfibers furnished by Phillips Fibers Corp.

Photograph 100. — Completed canal section.

Test Section 8. —

Material:	3-inch shotcrete reinforced with Fibermesh polyfibers
Date installed:	February 1992
Location:	Station 30+00 to 35+00 (500 linear feet; 30,000 square feet)
Description:	Polyfibers are Fibermesh Harbourite 320 (¾-inch-long fibrillated polypropylene fibers). Shotcrete work was performed in accordance with ACI 506.2 Specification for Materials, Proportioning, and Application of Shotcrete. Shotcrete cover was applied by the wet-mix process using 7-sack pea-gravel pump mix (94 lb of cement per sack, ⅜-in maximum aggregate size).
Prime Contractor:	Johnson Western Gunite Co.
Material Supplier:	Fibermesh Company
Subgrade Preparation:	Minimal subgrade preparation. The irrigation district removed large boulders (≥6 inches) from the canal bottom, but did little else prior to applying the shotcrete lining.
Construction:	The first 250 feet of shotcrete contained 3 lb/yd^3 of fiber; the second 250 feet contained and 1½ lb/yd^3. The shotcrete was left with an "as shot" or nozzle finish. The shotcrete was sprayed with curing compound and, as needed, covered with light tarps for 3 days to prevent freezing.
Difficulties:	Installers had difficulty applying a uniform 3-inch shotcrete layer. The irregular shotcrete thickness is not in itself detrimental; however, it increases the chance for thin spots that will need repair in the future. The fibers were noticeable at 3 lb/yd^3 and may have increased the water demand of the shotcrete mix.
Unit cost estimate:	$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.
Advantages:	Shotcrete can be applied over very irregular subgrade with little or no subgrade preparation. The polyfibers may decrease the amount of visible shotcrete cracking and improve durability. Shotcrete provides a hard wearing surface that is not susceptible to vandalism or animal damage, and allows the operation of maintenance equipment in the canal prism.
Disadvantages:	Seepage is expected to increase over the years as the shotcrete ages and cracks.
Photographs:	83 through 94 (general application) and 101 through 104 (test section 8)

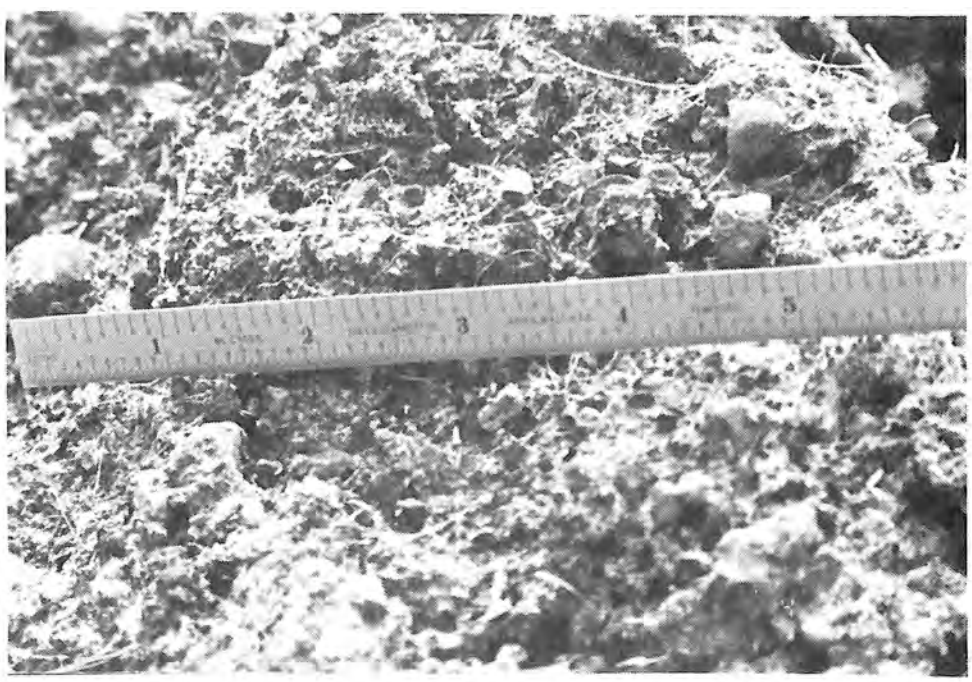
North Unit Main Canal
Test Section 8
3-inch shotcrete reinforced with Fibermesh polyfibers

POLYPROPYLENE FIBRILLATED FIBER
REINFORCEMENT

BY

FIBERMESH COMPANY

Photograph 101. — Polyfibers furnished by Fibermesh Co.



Photograph 102. — Polyfibers embedded in shotcrete.

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

Photograph 103. — Completed canal section.

Photograph 104. — Contractor marked the locations of different fiber dosage in the shotcrete.

Test Section 9. —

Material: 3-inch unreinforced shotcrete

Date installed: February 1992

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

Description: Shotcrete work was performed in accordance with ACI 506.2 Specification for Materials, Proportioning, and Application of Shotcrete. Shotcrete cover was applied by the wet-mix process using 7-sack pea-gravel pump mix (94 lb of cement per sack, 3/8-in maximum aggregate size).

Prime Contractor: Johnson Western Gunite Co.

Material Supplier: None. Shotcrete was purchased locally from two different batch plants at full market price.

Subgrade Preparation: Minimal subgrade preparation was performed. The irrigation district removed large boulders from the canal bottom, but little else was done prior to applying the shotcrete lining.

Construction: The shotcrete was left with an "as shot" or nozzle finish. The shotcrete was sprayed with curing compound and, as needed, covered with light tarps for 3 days to prevent freezing.

Difficulties: Installers had difficulty applying a uniform 3-inch layer of shotcrete. The irregular shotcrete thickness is not in itself detrimental; however, it increases the chance for thin spots that will need repair in the future.

Unit cost estimate: $1.33 per square foot

Advantages: Shotcrete can be applied over very irregular subgrade with little or no subgrade preparation. Shotcrete provides a hard wearing surface that is not susceptible to vandalism or animal damage, and allows the operation of maintenance equipment in the canal prism.

Disadvantages: Seepage is expected to increase over the years as the shotcrete ages and cracks.

Photographs: 105 and 106

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

Photograph 105. — Completed canal section.

Photograph 106. — Contractor marked the locations of different weights of fiber reinforcement in the shotcrete.

CHAPTER 3
OPTIONS TO REDUCE CONSTRUCTION COSTS

This study focused partly on identifying **low-cost**, effective lining systems. The unit costs of most of the linings installed ranged between $1.00 and $2.00 per square foot. These costs are not exorbitant, but viable modifications could reduce the unit costs even further:

- **Use Irrigation District Labor.** — Because most of the actual construction was performed by specialty contractors under Reclamation specifications, the contractors were required to pay wage board rates for the laborers. These wages typically are higher than the prevailing rate in rural construction areas. Therefore, the irrigation districts could reduce construction costs by administering the contracts themselves, or save even more by installing the liners with their own forces.

- **Shotcrete.** — Many of the lining systems used a 3-inch shotcrete liner either with or without a geomembrane underliner. These systems were among the most cost effective.

  Equipment. — The Kittitas Reclamation District, along with several other irrigation districts in central Washington, purchased their own shotcrete equipment and are experimenting with applying shotcrete lining using their own labor forces. This practice not only reduces the cost of shotcrete lining, but also gives the irrigation district the flexibility to schedule the lining during periods of good weather and when district personnel are available.

  Thickness. — The central Washington irrigation districts have relatively smooth canal subgrade conditions. Therefore, the districts are only applying a 2-inch shotcrete lining. However, for irregular subgrades, such as those found in the upper Deschutes River basin, a 3-inch shotcrete lining is needed to ensure adequate lining thickness.

- **Line Canal Bottom Only.** — Because the bulk of the seepage occurs downward, significant water savings could theoretically be achieved at a reduced cost by lining only the canal bottom (Morrison and Starbuck, 1984). This statement is especially true for wide and shallow canals such as those in Central Oregon.

- **Geocomposites.** — Installation of geocomposites (such as geotextile bonded to geomembrane) facilitates installation. Furthermore, friction between geotextile and geomembrane is sometimes critical and necessitates use of geocomposites. The additional cost of geocomposites is well justified in those instances. However, when friction between components is not critical, the additional cost usually cannot be justified.

- **Earthwork.** — The importation and placement of suitable subgrade material for geosynthetic liners was very labor intensive. However, Reclamation found this earthwork to be cost effective, allowing the use of less expensive, i.e., thinner, geosynthetics.

- **Non-Specialty Liners.** — Many lining systems do not require a specialty contractor, and can be installed by the irrigation district using their own personnel. In fact, district workers could install nearly all the lining systems tested in this project with minimal training.

CHAPTER 4
SEEPAGE ANALYSIS

Pre-construction Ponding Tests

Ponding tests were conducted to determine pre-construction seepage rates on two sites on the Arnold Canal and one site on the North Unit Main Canal.[1] Figure 5 shows the locations of the three ponding test sites.

Arnold Canal. —

Arnold Irrigation District conducted pre-construction seepage tests in March 1991. Reclamation surveyed canal cross sections and profiles from the railroad crossing to the Knott Road crossing (fig. 5). The ponding test sites were tied to these survey data.

To create the test ponds, district staff constructed earth dikes at the downstream end of each site. The canal bottom gradients limited the upstream end of the ponds. The dike for the upstream site was constructed at survey station 22+48, and a staff gauge was installed at station 20+00. The ponded reach extended about 2,500 feet. The dike for the downstream site was constructed at survey station 82+87, and the staff gauge was installed at station 80+67. This ponded reach extended about 3,600 feet. Depth of ponded water was typically about 2 feet.

On the afternoon of March 12, 1991, the district diverted water to the canal to fill the test ponds. The upstream dike was overtopped to fill the downstream test pond. Flow was cut off the morning of March 13, and some repairs were made to the dikes. By 2:30 p.m., the ponds had stabilized and flow over the dikes had stopped. The staff gauges were used to record the change in water elevation over time. The upstream pond was dry after about 30 hours and the downstream pond after about 40 hours, indicating high seepage rates. Tests were completed by the morning of March 15. Ponding test site conditions are shown in photographs 107 and 108.

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[1] In a ponding test, a section of canal is dammed and filled with water (ponded). The rate at which the water seeps from the ponded area is then measured over a period of time (typically 1 to 7 days).

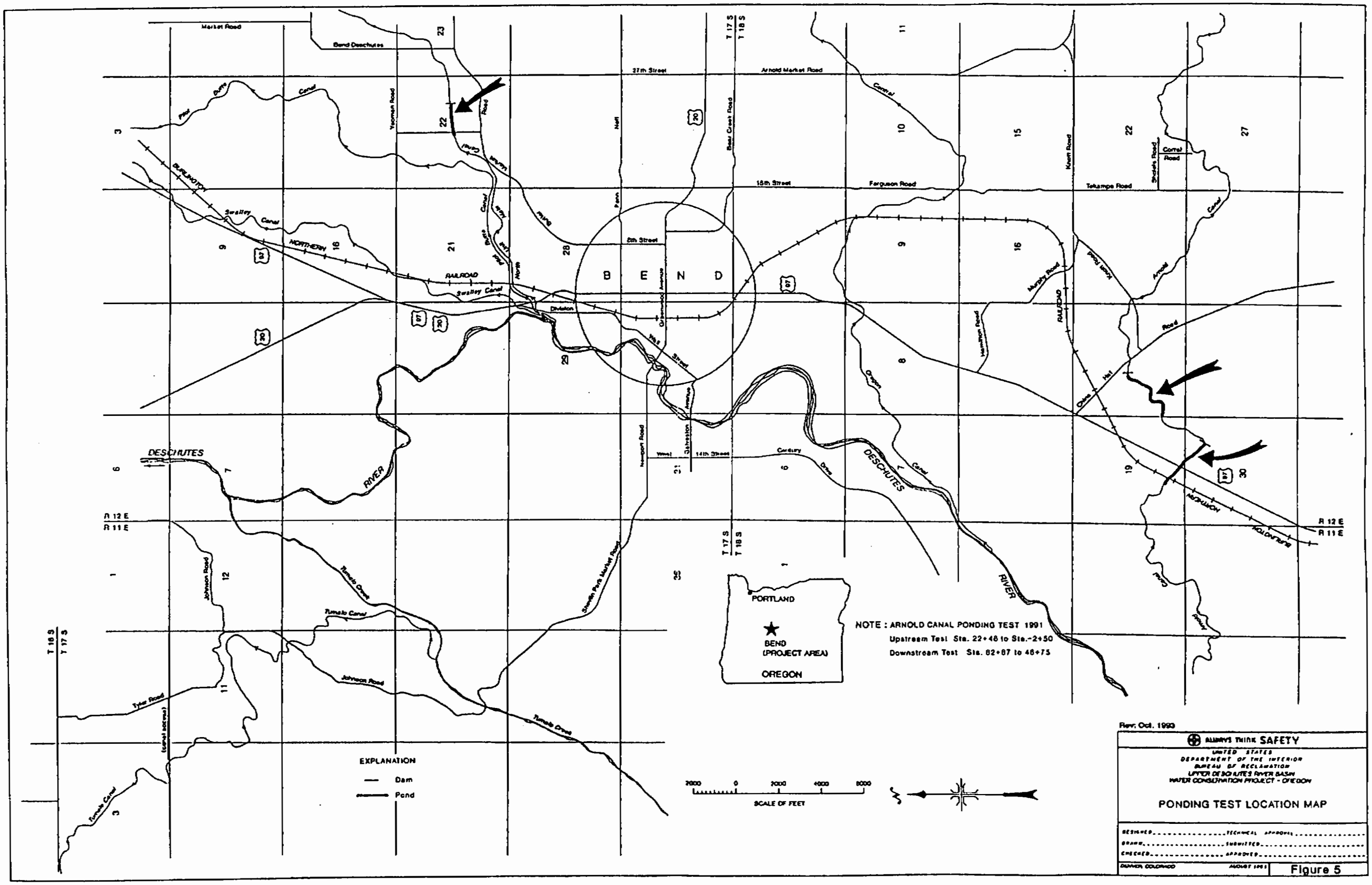


Figure 5. — Locations of the three ponding test sites.

Arnold Canal
Pre-construction Ponding Tests

Photograph 107. — Ponding test site No. 1. View from canal, looking downstream. Dike was located in line with tree stump on right side of canal.

Photograph 108. — Ponding test site No. 2. View from canal, looking downstream. Dike was located approximately in line with truck on left side of canal.

North Unit Main Canal. —

North Unit Irrigation District also conducted pre-construction ponding tests on its canal in March 1991. Reclamation collected survey data on the area extending from Yeoman Road to the Bend Deschutes Market Road (figs. 4 and 5). The ponding test site was tied to these data.

A 6-inch-thick concrete dam was constructed across the canal at survey station 12+22. The ends of the dam were tied to a set of old bridge abutments that were part of the canal walls. The upper end of the pond was controlled by a natural rock drop located near Yeoman Road. The ponded reach extended about 1,400 feet. Depth of the ponded water was typically 1 to 2 feet.

The district diverted water to the canal the morning of March 26. The pond filled by 1 p.m., and flow over the dam was stopped. Staff gauges, located at survey station 09+66 and 03+42, were read as water seeped from the test pond. By 9:30 a.m. on March 27, the pond was dry. Water was then diverted to the canal to refill the test pond for a second run. The pond refilled by 1:45 p.m. and was dry by noon on March 28. For both test runs, the pond was dry in less than 24 hours, indicating extremely high seepage rates. Ponding test site conditions are shown in photographs 109 and 110.

Seepage Rates

Seepage results from the movement of water through canal banks and bottoms. This loss is expressed in terms of the volume of water lost through a specific area of wetted canal surface in a specific period of time, normally in cubic feet of water passing through 1 square foot of canal surface per day ($ft^3/ft^2 \cdot day$). This expression allows comparison of losses in canals of similar material but of different widths, depths, and lengths.

Seepage rates for the Arnold and North Unit Main Canals were calculated using the cross-section survey data and the ponding test data. For each test pond and staff gauge measurement, a computer program generates:

(1) the volume of the water,
(2) the wetted area (the canal surface area in contact with water, including the canal bottom and sides),
(3) the change in volume of water with time, and
(4) average wetted area during the test. The following equation is used to estimate seepage rates.

Seepage = average volume (ft^3) of water lost per average area (ft^2) of wetted canal per day.

North Unit Main Canal
Pre-construction Ponding Tests

Photograph 109. — Ponding test site. View from canal, looking downstream. Dike was located in line with old bridge structure on left side of canal.

Photograph 110. — Canal at ponding test area with water flowing. View looking upstream.

Following are the range of canal seepage rates and average seepage rates for the three test sites.[2]

Arnold Pond A - downstream pond
Seepage rates = 0.54 to 0.69 $ft^3/ft^2 \cdot day$
Average seepage rate = 0.64 $ft^3/ft^2 \cdot day$

Arnold Pond B - upstream pond
Seepage rates = 1.34 to 1.55 $ft^3/ft^2 \cdot day$
Average seepage rate = 1.40 $ft^3/ft^2 \cdot day$

North Unit Pond - both runs
Seepage rates = 3.14 to 5.40 $ft^3/ft^2 \cdot day$
Average seepage rate = 4.20 $ft^3/ft^2 \cdot day$

These seepage results indicate high rates of seepage for canals in the Bend area. The results also indicate that seepage rates vary greatly from district to district and even within the same district. Typical seepage rates for various geologic conditions are shown in table 5 (Reclamation, 1948; Reclamation, 1963; Davis and Wilson, 1919). See appendix E for further comparison.

Table 5. - Typical canal seepage rates.

Geologic Conditions	Seepage Rate ($ft^3/ft^2 \cdot day$)
Canal with 3-to 4-inch concrete liner (with good joint filler)	0.07
Canal in clay and clay loam	0.41
Canal in volcanic ash	0.68
Canal in sand and volcanic ash	1.20
Canal in sand and gravelly sand	2.20

The seepage rates for both Arnold test ponds are within the expected range. However, the seepage rate for the North Unit test pond is much higher than expected, and suggests the presence of a localized fissure or sinkhole. Therefore, the typical seepage rates shown in table 5 may be used to estimate seepage rates based on geologic conditions, but until more seepage tests are performed in different areas of the Deschutes River Basin, seepage analysis can only be considered a best guess estimate.

[2] Arnold Pond A corresponds to Arnold test sections 4 through 10, inclusive. Arnold Pond B corresponds to Arnold test sections 1 through 3, inclusive.

Post-construction Ponding Tests

Arnold Canal. —

In April 1993, ponding tests were conducted on each of the ten test sections on the Arnold Canal to determine the effectiveness of the linings in reducing seepage. Ponded water depth was typically 1 to 2 feet. Table 6 shows the seepage rates calculated for the ten sections.

Table 6. - Arnold Canal—post-construction seepage rates.

Test section	Lining material	Seepage rate ($ft^3/ft^2 \cdot day$)
1	Petromat MB II with 3-inch shotcrete cover	0.05
2	30-mil VLDPE textured geomembrane with 3-inch unreinforced shotcrete cover and 16-ounce geotextile cushion	0.11
3	60-mil HDPE texture geomembrane	0.00
4	Geolam with 6-ounce geotextile cushion	0.00
5	45-mil Hypalon with 16-ounce geotextile cushion	0.01
6	Exposed 36-mil Terra-Tuff	0.12
7	40-mil PVC with 3-inch grout-filled mattress	0.10
8	3-inch grout-filled mattress	0.02
9	Exposed 60-mil VLDPE with 3-inch grout-filled mattress on side slopes only	0.07
10	Exposed 60-mil HDPE with 3-inch grout-filled mattress on side slopes only	0.07

The post-construction seepage rates range from 0.00 to 0.12 $ft^3/ft^2 \cdot day$. The majority of the seepage rates were less than 0.07 $ft^3/ft^2 \cdot day$. These results indicate that all of the test sections have quite low seepage rates. Differences between individual test sections are not considered significant and are probably caused by experimental error such as seepage through dikes. Photographs 111 through 114 show post-construction ponding tests on the Arnold Canal.

North Unit Main Canal. —

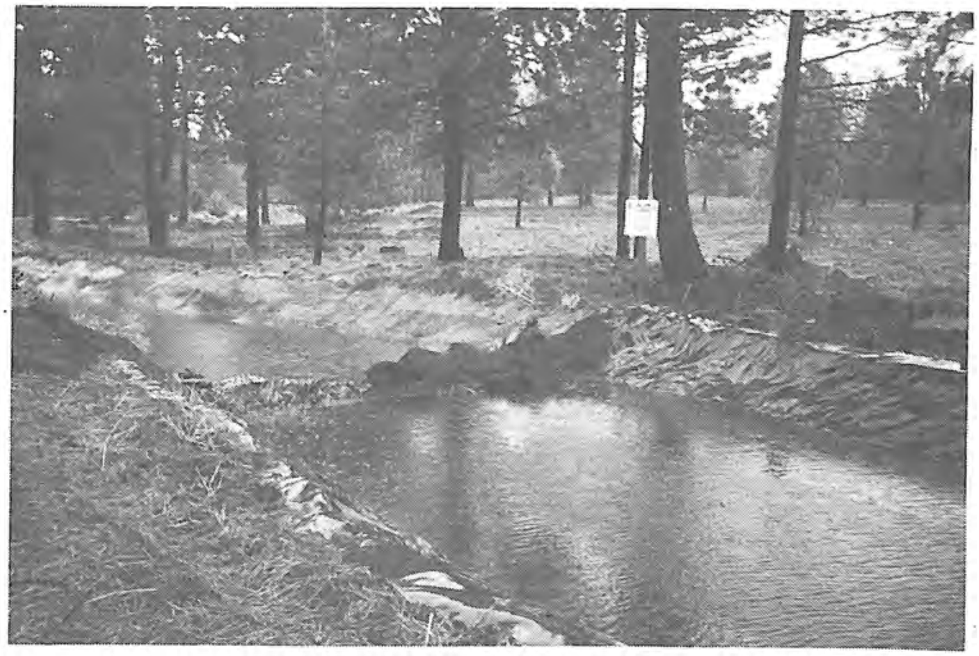
Post-construction ponding tests on the eight North Unit test sections are scheduled for spring 1994.

Arnold Canal
Post-construction Ponding Tests

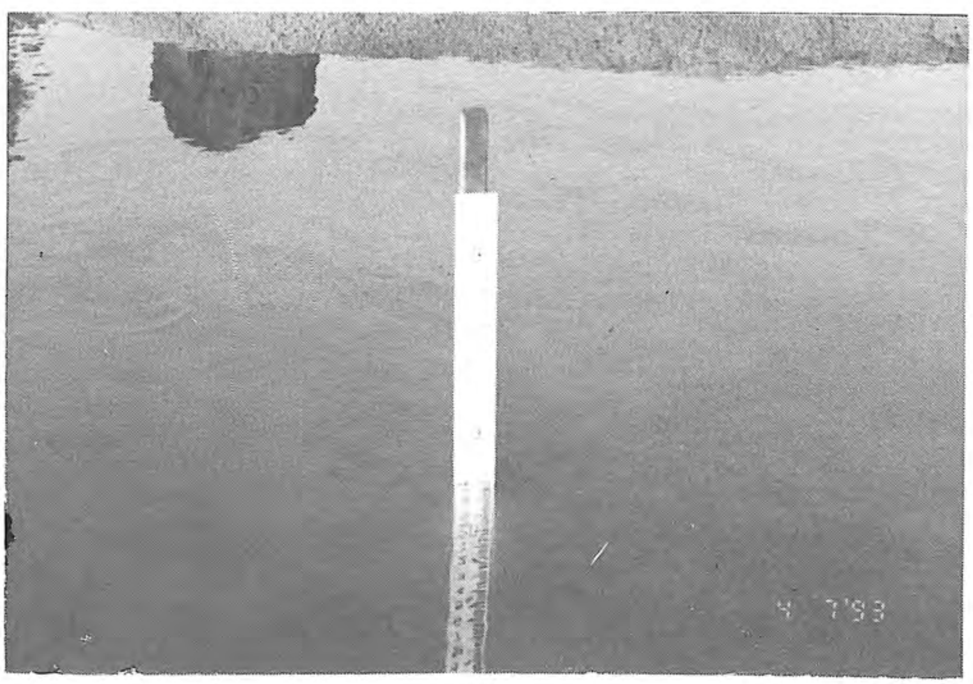
Photograph 111. — Typical dike construction for ponding tests over installed materials.

Photograph 112. — Water levels in upstream and downstream ponds are almost the same.

Arnold Canal
Post-construction Ponding Tests



Photograph 113. — Water levels in upstream and downstream ponds are notably different.



Photograph 114. — Staff gauge in pond readings are only accurate to 0.01 foot.

CHAPTER 5
PROJECTED WATER SAVINGS AND COSTS

The amount of water that can be saved by canal linings equals the difference between seepage rates before lining and after lining. Table 7 summarizes the potential water savings for the Arnold and North Unit test sections based on a 180-day irrigation season and our typical post-construction seepage rate (0.07 $ft^3/ft^2{\cdot}day$).

Table 7. - Potential water savings.

Canal Test Section	Seepage Before Lining ($ft^3/ft^2{\cdot}day$)	Seepage After Lining ($ft^3/ft^2{\cdot}day$)	Water Savings ($ft^3/ft^2{\cdot}day$)	Water Savings (acre-ft/$ft^2{\cdot}yr$)
Arnold A	0.64	0.07	0.57	0.0024
Arnold B	1.40	0.07	1.33	0.0055
North Unit	4.20	0.07	4.13	0.0171

To determine the cost of this conserved water, the annualized life-cycle costs for the various canal linings must be estimated. As stated previously, life-cycle costs consist of initial construction costs, design life, and maintenance and repair costs.

Initial construction costs on this demonstration project mostly ranged from \$1.00 to \$2.00 per square foot (table 3). For illustration purposes, \$1.50/ft^2 will be used as a typical construction cost. The annualized construction cost depends on the interest rate and the design life (life of the liner). Using a 5-percent interest rate and design lives of 10, 20, and 30 years, the respective annualized construction costs are \$0.19/ft^2/year, \$0.12/ft^2/year, and \$0.10/ft^2/year. If maintenance costs are estimated at 4 percent per year, the annual maintenance cost is \$0.06/ft^2/year. The total annual cost (life-cycle cost) is the sum of the annualized construction and maintenance costs (i.e., \$0.25/ft^2/year,* \$0.18/ft^2/year, and \$0.16/ft^2/year). Dividing this total annual cost by the annual water savings yields the cost for each acre-foot of saved water.

Table 8. - Water costs.

Canal Test Section	Seepage Before Lining ($ft^3/ft^2{\cdot}day$)	Water Savings (acre-ft/$ft^2{\cdot}yr$)	Total Lining Cost (\$/$ft^2{\cdot}yr$)	Water Cost (\$/acre-ft)
Arnold A	0.64	0.0024		
10 yrs			0.25	104
20 yrs			0.18	75
30 yrs			0.16	67
Arnold B	1.40	0.0055		
10 yrs			0.25	45
20 yrs			0.18	33
30 yrs			0.16	29
North Unit	4.20	0.0171		
10 yrs			0.25	15
20 yrs			0.18	11
30 yrs			0.16	9

* To put a life-cycle cost of \$0.25/ft^2/year in perspective, the cost for lining and maintaining 1 mile of 30-foot-wide canal would be \$39,000/year.

As shown in table 8, the greatest benefit is obtained by lining those canal sections with the highest seepage rates. If the market value of water is $50/acre-foot, the above examples indicate that lining the North Unit and the Arnold B section is warranted. Lining the Arnold A section is not warranted because of its lower seepage rate. Costs of other seepage rates are listed in table 9 below (based on a 10-year design life). Note that for canals with low pre-construction seepage rates, the cost of the conserved water becomes prohibitive.

Table 9. - Costs of other seepage rates.

Seepage Before Lining ($ft^3/ft^2 \cdot day$)	Seepage After Lining ($ft^3/ft^2 \cdot day$)	Water Savings ($acre\text{-}ft/ft^2 \cdot yr$)	Total Lining Cost ($\$/ft^2 \cdot yr$)	Water Cost ($/acre-ft)
0.10	0.07	0.0001	0.25	2500
0.25	0.07	0.0007	0.25	357
0.50	0.07	0.0018	0.25	139
1.00	0.07	0.0038	0.25	66
1.50	0.07	0.0059	0.25	42
2.00	0.07	0.0080	0.25	31
2.50	0.07	0.0100	0.25	25
3.00	0.07	0.0121	0.25	21
3.50	0.07	0.0142	0.25	18
4.00	0.07	0.0162	0.25	15
4.50	0.07	0.0183	0.25	14
5.00	0.07	0.0204	0.25	12

These saved water costs depend on our assumptions for long-term seepage rates, design life, and maintenance costs, all of which will be further refined in future studies (see chap. 7).

CHAPTER 6
MATERIALS TEST RESULTS

Samples were taken of some of the lining materials to establish a baseline for future tests for strength and other characteristics. Appendix F includes laboratory test results.

- **Geosynthetics. —** No physical property tests are currently underway. Instead, future durability analysis will use the manufacturers' published physical properties (appendixes C and D) as baseline data. Samples of many of the geosynthetic lining materials have been retained for future comparison, if needed.

- **Shotcrete. —** Shotcrete test panels (1 foot by 1 foot by 3 inches) were "shot" at the job site. These panels were cored and tested for compressive strength one year later. The test results (included in appendix F) show good compressive strength [4,000 to 5,000 pounds per square inch (lbf/in^2)] for all the shotcrete/fiber mixes. The data also show that the greater the amount of fibers in the concrete, generally the lower the compressive strength. However, these slight differences in compressive strength are not significant.

  The fibers may increase shotcrete tensile strength and thereby reduce shotcrete shrinkage crack openings and improve long-term shotcrete durability. These effects will take several years to demonstrate.

- **Grout Mattress. —** Test results showed low compressive strength for all cement grout samples (2,000-2,500 lbf/in^2). Samples were taken from the ready-mixed concrete trucks for grout mixes both with and without fiber reinforcing. Samples included grout cast into conventional cylinders and into Armorform fabric "test socks" for comparison. ("Test socks" are fabric tubes fabricated from Armorform fabric). Tests were conducted to determine the difference in compressive strength resulting from the bleeding out of excess mixing water through the water-permeable Armorform fabric as compared with the sample cast in the impermeable conventional cylinder. Results were inconclusive, but have been included in appendix F.

- **Polyurethane Foam. —** Samples of the 2- and 5-pound polyurethane foam were collected from the job site. These samples were tested for density and compressive strength per ASTM D1621 "Compressive Properties of Rigid Cellular Plastics".

  The 2-pound foam was field applied in two 1-inch lifts. The laboratory test specimen included one lift line (skin) and showed a density of 2.3 lbm/ft^3 and a compressive strength of 35 lbf/in^2. The strength, density, and visual appearance indicate good quality 2-pound foam.

  The 5-pound foam was field applied in a single ½-inch lift and appeared to be of good quality but with an unusually thick skin. Tests on this foam (without the skin) showed an average density of only 2.1 lbm/ft^3 and an average compressive strength of 32 lbf/in^2. Test results are included in appendix F. The low density might be the result of field application problems caused by bad weather. In any case, the density and strength of the 5-pound foam appear to be far below what was specified. However, the small specimen size (less than ½ inch thick) makes the physical property tests on the 5-pound foam suspect.

CHAPTER 7
FUTURE STUDIES

Additional Test Sections

Three additional test sections are planned for 1994 and 1995. These planned test sections include an exposed Siplast (polymer-modified bituminous membrane) test section installed by irrigation district personnel, Liquid Boot (polymer-modified asphaltic emulsion) spray-applied to three metal flumes by irrigation district personnel, and a polypropylene geomembrane test section.

Durability Reports

These reports will document durability, maintenance, and design life for each test section. The irrigation districts will keep track of maintenance activities and costs and provide written documentation annually. The first durability report is being prepared and will assess the condition of each test section after 1 to 2 years of service. This first report will be available by fall 1994. Additional durability reports will be published every two years.

Seepage Studies

Additional studies are needed to better define the seepage rates both before and after lining, and to assess durability. Post-construction ponding tests on the North Unit Main Canal test sections are planned for spring or fall 1994. To determine long-term seepage rates, additional post-construction ponding tests on both the Arnold and the North Unit test sections are planned for 1998 (year 5) and/or 2003 (year 10). Finally, flow recorders are being installed on a 26-mile reach of the North Unit Main Canal to better quantify pre-construction seepage rates over three reaches measuring 5 miles, 5 miles, and 16 miles.

Final Report

The final report is scheduled for publication in 2003 (year 10). This report will provide long-term data on the design life, maintenance costs, life-cycle costs, long-term seepage losses, and the cost of conserved water for each test section.

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Appendix A

Evaluation of Proposals

ESDAY
, 1991

COMMERCE

Issue No. PSA-035

A daily list of U.S. Government procurement invitations, contract awards, subcontracting leads, sales of surplus property and foreign business opportunities

BUSINESS DAILY

DEPARTMENT OF COMMERCE · UNITED STATES OF AMERICA

U.S. GOVERNMENT PROCUREMENTS

...erce Business Daily publishes, for Federal agencies, synopses of proposed con...ts that exceed $25,000 in value.

A Research and Development - Potential Sources Sought

Bureau of Reclamation, Acquisition and Management, Box 043, 550 West Fort Street, Boise, Idaho 83724

A – IRRIGATION CANAL LINERS SOL 1-SP-10-0560 POC Contracting Officer, Devon Scott Shelley, 208/334-1683 Research and Development Sources Sought. All offerors capable of satisfying the Government's needs are being sought. This is a supplemental broad agency announcement to the announcement initially published on June 4, 1990 The Bureau of Reclamation, State of Oregon, and local interests are involved in a cooperative study in Oregon called the Upper Deschutes River Basin Water Conservation Project This research effort seeks to identify ways to conserve water in the irrigation system for enhancing Deschutes River stream flows and for reducing critical year water shortages to irrigated lands. The research involves the potential to line irrigation canals and save a substantial volume of water each year. The volcanic geology of the upper Deschutes River basin is significantly different than almost any other irrigated area in the United States Experts in canal lining processes believe that traditional lining technology is inappropriate and too expensive for application in the area. The research will be accomplished as a demonstration project to test a broad range of canal lining alternatives and determine the best alternatives for the area The primary purposes of the research are to consider each application for (1) the suitability to conditions (2) constructability (3) effectiveness in preventing seepage (4) durability (5) construction costs and (6) operation, maintenance, and replacement costs. This general announcement is primarily for the purpose of seeking out new technologies that are also cost effective. It is anticipated that multiple research and development contracts will be awarded from a single solicitation. The criteria for selecting proposals, and soliciting the participation of all offerors capable of satisfying the Government's needs include (1) Cost, to include demonstration cost, cost share, and basin-wide cost (2) Capability (3) Experience (4) Uniqueness and (5) Adequacy. Sources meeting the above criteria are requested to submit a written statement of capability and a request for

Issue No. PSA-0358; Wednesday, June 5, 1991

a copy of the Solicitation to Mr. Devon Scott Shelley U.S. Department of Interior, Bureau of Reclamation, Attention Code PN-820, Box 043 - 550 West Fort Street, Boise, ID 83724-0043. It is anticipated that the solicitation will be issued approximately June 19, 1991 with the first contract award projected for September 1991. The Standard Industrial Classification Code (SIC) is 8731. The size standard is 500 employees. Respondents should indicate whether or not your firm is a small business, small disadvantaged business, or woman owned business. (0154)

UPPER DESCHUTES RIVER BASIN CANAL LINING DEMONSTRATION PROJECT
TECHNICAL EVALUATION WORKSHEET

Proposal: ____________________

TECHNICAL

The proposal must be technically adequate, showing good engineering and science with respect to the following items: construction methods, construction time, damage resistance, durability, ease of repair, environmental friendliness, expected life, material properties, practicality, safety, seepage control, and toxicity.

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

(1) The proposal does not demonstrate good engineering and science. The proposed materials and processes will either not achieve the desired effect or lack adequate documentation to demonstrate a reasonable chance of success. The proposed action will result in adverse effects to the environment or to public safety and health.

(2)

(3)

(4)

(5) The proposal clearly shows technical adequacy. The proposed materials and processes have been demonstrated in other applications or a well documented plan is presented that will ensure a very good chance that the proposed application will be successful. All proposed processes associated with the application represent good engineering and science. The proposed action will not result in adverse effects to the environment or to public safety and health.

Score: ____

Evaluator's Comments:

UPPER DESCHUTES RIVER BASIN CANAL LINING DEMONSTRATION PROJECT
TECHNICAL EVALUATION WORKSHEET

Proposal: ____________________

CAPABILITY

Potential demonstration project participants need to demonstrate their experience or ability to supply, provide installation oversight, and successfully install the proposed application.

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

(1) The proposal lacks information regarding the firm's experience or capability to supply and install its proposed application. No information on previous supply and installation experience is presented. No plan is displayed describing how the firm intends to get the required material, equipment, and labor on-site and how it will install, or ensure the installation of, the proposed application.

(2)

(3)

(4)

(5) The proposal adequately documents the firm's experience to supply and install its proposed application. The proposal contains documentation of previous, successful installations of its application. The proposal clearly describes how the firm will get all the required material, equipment, and labor on-site and how it will install, or ensure the installation of, the proposed application.

Score: _____

Evaluator's Comments:

UPPER DESCHUTES RIVER BASIN CANAL LINING DEMONSTRATION PROJECT
TECHNICAL EVALUATION WORKSHEET

Proposal: ____________________

NEW MATERIALS OR APPLICATIONS

One purpose of the demonstration project is to identify new canal lining technologies. This could include a new material or a new application of an existing material.

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

(1) The proposal contains neither a new canal lining material nor is it a new application of a previously used material.

(2)

(3)

(4)

(5) The proposal brings a new material or a new application processes to the lining of irrigation canals.

Score: ___

Evaluator's Comments:

UPPER DESCHUTES RIVER BASIN PROJECT
TECHNICAL PROPOSAL EVALUATION

Firm	Test Section	Capability			Adjusted Capability Score	Technical			Adjusted Technical Score	Material			Adjusted Material Score	Total Score
		A	B	C		A	B	C		A	B	C		
Environmental Liners	Arnold 4	4	5	5	23.33	5	5	5	50.00	4	5	4	21.67	95.00
Environmental Liners	Arnold 5	4	5	5	23.33	5	5	5	50.00	4	5	4	21.67	95.00
Environmental Liners	Arnold 6	4	5	5	23.33	5	5	5	50.00	4	5	4	21.67	95.00
Holten Enterprises, Inc.	North 1	4	2	4	16.67	4	4	2	33.33	4	3	5	20.00	70.00
Holten Enterprises, Inc.	North 2	4	2	4	16.67	4	4	2	33.33	4	3	5	20.00	70.00
Holten Enterprises, Inc.	North 3	4	2	3	15.00	4	3	2	30.00	5	5	5	25.00	70.00
Holten Enterprises, Inc.	North 4	4	2	3	15.00	4	3	2	30.00	5	5	5	25.00	70.00
Pacific Erosion Control	Arnold 7	5	5	4	23.33	3	2	2	23.33	3	4.5	4	19.17	65.83
Johnson Western Gunite/Phillips	Arnold 1	3	2	3	13.33	3	2	4	30.00	3	4	4	18.33	61.67
Johnson Western Gunite/Gundle	Arnold 2	4	3	5	20.00	4	3	1	26.67	2	4	1	11.67	58.33
Johnson Western Gunite/Gundle	Arnold 3	4	3	5	20.00	4	3	1	26.67	2	4	1	11.67	58.33
Johnson Western Gunite/Steel Fibers	North 6	3	2	3	13.33	3	2	3	26.67	2	4	3	15.00	55.00
Johnson Western Gunite/Fibermesh	North 8	3	2	3	13.33	3	2	3	26.67	3	4	2	15.00	55.00
Aqua Construction	Not used	3	2	3	13.33	3	2	2	23.33	4	2	3	15.00	51.67
Johnson Western Gunite/PP Fibers	North 7	3	2	3	13.33	3	2	3	26.67	2	2	2	10.00	50.00
Canamer/60 mil VLDPE	Arnold 9	3	1	2	10.00	3	2	1	20.00	3	5	1	15.00	45.00
Canamer 60 mil HDPE	Arnold 10	3	1	2	10.00	3	2	1	20.00	3	4	1	13.33	43.33
Johnson Western Gunite/Shotcrete	North 9	3	2	3	13.33	3	2	2	23.33	1	1	1	5.00	41.67
Canamer/Grout Mattress only	Arnold 8	3	1	2	10.00	3	2	1	20.00	2	2	1	8.33	38.33
George Ward Pozzolan	North 5													

Appendix B

Cost Estimates
Subgrade Preparation

ESTIMATE WORKSHEET

FEATURE Canal Lining Demonstration Test Section Cost for Minimal Earthwork 100,000 sq. feet	PROJECT Upper Deschutes R. Basin Water Con. Project, OR
	DIVISION Planning Division
COMPANY	UNIT

Plant Account	Pay Item	Description	Code	Quantity	Unit	Unit Price	Amount
	1	Mobilization & preparatory work		Lump sum	l.s.	l.s.	100
	2	Remove loose rock from canal		150	yd3	10.00	1,500
	3	Weed and Shrub Removel		2	ac	500.00	1,000
	4	Unlisted items 10%		Lump sum	l.s.	l.s.	300
		Subtotal					2,900
		Contingencies 20%					600
		Field Cost					3,500
		Price per sq. foot					$0.04

ESTIMATE WORKSHEET

FEATURE	PROJECT
Canal Lining Demonstration Test Section Cost for Moderate Earthwork 100,000 sq. feet	Upper Deschutes R. Basin Water Con. Project, OR
	DIVISION Planning Division
COMPANY	UNIT

Plant Account	Pay Item	Description	Code	Quantity	Unit	Unit Price	Amount
	1	Mobilization & preparatory work		Lump sum	l.s.	l.s.	400
	2	Remove loose rock from canal		150	yd3	10.00	1,500
	3	Redistribute subgrade material		250	yd3	20.00	5,000
	4	Weed and Shrub Removel		2	ac	1000.00	2,000
	5	Unlisted items 10%		Lump sum	l.s.	l.s.	900
		Subtotal					9,800
		Contingencies 20%					2,000
		Field Cost					11,800
		Price per sq. foot					$0.12

ESTIMATE WORKSHEET

FEATURE	PROJECT
Canal Lining Demonstration Test Section Cost for Extensive Earthwork 100,000 sq. feet	Upper Deschutes R. Basin Water Con. Project, OR
	DIVISION Planning Division
COMPANY	UNIT

Plant Account	Pay Item	Description	Code	Quantity	Unit	Unit Price	Amount
	1	Mobilization & preparatory work		Lump sum	l.s.	l.s.	900
	2	Remove loose rock from canal		150	yd3	10.00	1,500
	3	Furnishing & placing subgrade material		600	yd3	25.00	15,000
	4	Weed and Shrub Removel		2	ac	1000.00	2,000
	5	Unlisted items 10%		Lump sum	l.s.	l.s.	1,900
		Subtotal					21,300
		Contingencies 20%					4,300
		Field Cost					25,600
		Price per sq. foot					$0.26

Appendix C

Manufacturers' Data Sheets
Arnold Canal

Ensure materials and surrounding air temperature are maintained at a minimum 35 degrees F during and 3 days after placement of shotcrete.

B. During freezing weather provide cover to maintain shotcrete at or above 35 degrees F.

PART II -- PRODUCTS

2.01 Materials

A. Cement: ASTM C150 Type I or II.

B. Sand and Gravel: ASTM C-33

C. Water: Potable

D. Additives: Water reducing and Air Entraining only per ASTM

E. Reinforcement: Steel Fibers per ASTM C1116 and ASTM A820 Type I

2.02 Mix Proportions

A. Conform to following requirements:

1. Compressive strength (28 days) - 2500 PSI

2. Cementitious Materials - 610 pounds per cubic yard minimum

3. Aggregate size (maximum) - 1/2 inch

4. Air entrainment: 4-6 percent at truck discharge.

5. Chemical Admixture: Water Reducing, Pozzolon

6. Pozzolanic mineral admixture: Allowed

7. Slump: 2 inches minimum wet-mix

8. Steel Fibers: Use 25 pounds per cubic yard for 1/2 of job and 50 pounds for 1/2 of job.

B. Ensure thorough mixing of materials. If wet mix is used follow requirements of ASTM C-94 for delivery and mixing.

2.03 Equipment- Wet-Mix

1. Mixing Equipment: Capable of thoroughly mixing aggregate, cement, and water in sufficient quantity to maintain continuous placement.

2. Air Supply: Clean air adequate for maintaining sufficient nozzle velocity for all parts of the work.

MOISTURE BARRIER SPECIFICATION

FOR BASE STABILIZATION APPLICATIONS

COMPOSITE OF POLYETHYLENE FILM BETWEEN TWO NONWOVEN POLYPROPYLENE FABRIC LAYERS

FEBRUARY 1992

PROPERTY	STANDARD TEST PROCEDURE	WEAKEST DIRECTION VALUE	SPECIAL TEST INFORMATION	PETROMAT MB II L17781
WEIGHT ounces/square yard	ASTM D-3776	MINIMUM	CERTIFIABLE	9.0
TENSILE STRENGTH pounds	ASTM D-4632	MINIMUM	CERTIFIABLE	150
ELONGATION percent	ASTM D-4632	MINIMUM	CERTIFIABLE	40
PUNCTURE STRENGTH pounds	ASTM D-4833	MINIMUM	CERTIFIABLE	80
MULLEN BURST STRENGTH, psi	ASTM D-3786	MINIMUM	CERTIFIABLE	260
TRAPEZOIDAL TEAR STRENGTH, pounds	ASTM D-4533	MINIMUM	CERTIFIABLE	45
ABRASION RESISTANCE % strength retained both sides	ASTM D-4886	MINIMUM	CERTIFIABLE	60
COEFFICIENT of PERMEABILITY, cm/sec	ASTM D-4491	MINIMUM	CERTIFIABLE	0
FLOW RATE gpm/sf	ASTM D-4491	MINIMUM	CERTIFIABLE	0
PERMITTIVITY per second	ASTM D-4491	MINIMUM	CERTIFIABLE	0
STANDARD ROLL SIZES	144 INCHES WIDE	LINEAR YARDS SQUARE YARDS		100 400

Phillips Petromat MB II meets these specifications. For further information, call 1-800-374-6606. Ask for Petromat MB Dept.

PHILLIPS FIBERS CORPORATION
A SUBSIDIARY OF PHILLIPS PETROLEUM COMPANY
ENGINEERED PRODUCTS MARKETING
P.O. BOX 66. GREENVILLE, SC 29602 (803) 242-6600

2210-2RK

FI-CON™ polypropylene fibers

FIBERS additive for portland cement concrete

FACT SHEET

No. 1 January 1991

FI-CON* POLYPROPYLENE FIBER (PCC ADDITIVE) BY PHILLIPS

FI-CON™ is specifically engineered by Phillips for reducing shrinkage cracks in portland cement concrete.

FI-CON™ is added to the concrete mix and is a simple, effective, and economical method of reducing the formation of plastic settlement in concrete.

FI-CON™ is made of tough polypropylene—known and proven for the outstanding performance characteristics it adds to pcc.

Major benefits **FI-CON™** brings to pcc include:

- Reduces shrinkage cracks
- Reduces permeability to moisture and chlorides
- Increases compressive strength, flexural strength, and splitting tensile strength
- Increases fatigue resilience
- Greater impact resistance

Properties of FI-CON™

Diameter (denier)	0.0019″ (15 denier)
Length	3/4″
Specific gravity	0.90-0.91
Tensile strength (tenacity)	>40,000 psi
Elongation	>60%
Moisture regain (70°F, 65% RH)	less than 0.1%
Material	polypropylene
Effect of extreme cold	polypropylene remains flexible at –100°F

FI-CON™ polypropylene fibers are inert, water insoluble, and remain dimensionally stable with changes in humidity. They are durable and offer excellent chemical, weather, and abrasion resistance. Polypropylene is superior to polyester in high alkaline conditions such as those experienced in pcc. Additionally, polypropylene is highly soil and stain resistant and resistant to bacterial attack (does not support growth of mildew or fungi).

INFORMATION

FI-CON™ is manufactured by Phillips Fibers Corporation, producer of Marvess® (polypropylene) olefin fiber and yarn for a wide range of consumer and industrial applications and manufacturer of nonwoven fabrics and geotextiles. For further information contact Phillips Fibers Corporation, P.O. Box 66, Greenville, SC 29602, attention Engineered Products Marketing. Call 803-242-6600 or 800-845-5737.

PHILLIPS 66

PHILLIPS FIBERS CORPORATION
A SUBSIDIARY OF PHILLIPS 66 COMPANY
ENGINEERED PRODUCTS MARKETING
P.O. BOX 66, GREENVILLE, SC 29602 (803) 242-6600

GUNDLE HYPERLASTIC VLDPE SPECIFICATIONS

Gundle Hyperplastic is a special formulation of very low density polyethylene containing approximately 97.5% polymer and 2.5% carbon black, anti-oxidants and heat stabilizers.

TYPICAL PROPERTIES*	TEST METHOD	GAUGE (NOMINAL)					
		20 mil (0.5 mm)	30 mil (0.75 mm)	40 mil (1.0 mm)	60 mil (1.5 mm)	80 mil (2.0 mm)	100 mil (2.5 mm)
Tensile Properties. (Typical)							
1. Tensile Strength at Break (Pounds inch width)	ASTM D638 Type IV Dumb-bell at 2 ipm	63	94	126	180	200	250
2. Elongation at Break (Percent)		900	900	900	900	900	900
Puncture Resistance. Pounds. (Typical)	FTMS 101 Method 2065	38	51	64	72	80	88
Tear Resistance Initiation. Pounds. (Typical)	ASTM D1004 Die C	10	12	18	24	30	35
Dimensional Stability. % Change. Each Direction. (Max.)	ASTM D1204 212°F 1 hr.	±2	±2	±2	±2	±2	±2
Low Temperature Brittleness. °F (Typical)	ASTM D746M Procedure B	−112	−112	−112	−112	−112	−112
Resistance to Soil Burial. Percent change in original value. (Typical) Tensile Strength at Break.	ASTM D3083 Type IV Dumb-bell at 2 ipm	±10	±10	±10	±10	±10	±10
Environmental Stress crack. Hours. (Min.)	ASTM D1693 10% Igepal, 50°C	1500	1500	1500	1500	1500	1500

*Note: All values, except when specified as minimum or maximum, are typical test results.

SUPPLY SPECIFICATIONS

The following describes typical roll dimensions for Hyperlastic VLDPE

THICKNESS		WIDTH		LENGTH		AREA		ROLL WEIGHT	
mil	mm	ft.	m	ft.	m	ft.²	m²	lb.	kg.
20	0.5	22.5	6.86	1250	381	28,125	2613	2800	1272
30	0.75	22.5	6.86	840	256	18,900	1756	2800	1272
40	1.0	22.5	6.86	650	198	14,625	1359	2800	1272
60	1.5	22.5	6.86	420	128	9,450	878	2800	1272
80	2.0	22.5	6.86	320	98	7,200	670	2800	1272
100	2.5	22.5	6.86	250	76	5,625	522	2800	1272

HYPERLASTIC is rolled on 6" I.D. hollow cores. Each roll is provided with 2 slings to aid handling on site. Dimensions and weights are approximate. Custom lengths available on request.

Gundle Lining Systems Inc.

19103 Gundle Road
Houston, Texas 77073 U.S.A.

Phone: (713) 443-8564
Toll Free: (800) 435-2008
Telex: 4620281 GundleHou
Fax: (713) 875-6010

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

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GUNDLINE® HDT SHEET SPECIFICATIONS

TYPICAL PROPERTIES*	TEST METHOD	GAUGE (NOMINAL)			
		40 mil (1.0 mm)	60 mil (1.5 mm)	80 mil (2.0 mm)	100 mil (2.5)
Tensile Properties (Typical)	ASTM D638 Type IV Dumb-bell at 2 ipm.				
1. Tensile Strength at Break (Pounds/inch width)		23	35	46	56
2. Tensile Strength at Yield (Pounds/inch width)		84	126	168	210
3. Elongation at Break (Percent)		100	100	100	100
4. Elongation at Yield (Percent)		13	13	13	13
Tear Resistance Initiation. Pounds. (Typical)	ASTM D1004 Die C	30	45	60	75
Puncture Resistance. Pounds. (Typical)	FTMS 101 Method 2065	45	70	95	110

*(*Note: All values are typical test results.)*

SUPPLY SPECIFICATIONS

The following describes typical roll dimensions for Gundline HDT

NOMINAL THICKNESS		WIDTH		LENGTH		AREA		ROLL WEIGHT	
mil	mm	ft.	m	ft.	m	ft.²	m²	lb.	kg.
40	1.0	22.5	6.86	500	152	11,250	1045	2780	1261
60	1.5	22.5	6.86	420	128	9,450	878	3270	1483
80	2.0	22.5	6.86	320	97	7,200	669	3200	1452
100	2.5	22.5	6.86	250	76	5,625	522	3056	1386

HYPERLASTIC® TEXTURED SHEET SPECIFICATIONS

TYPICAL PROPERTIES*	TEST METHOD	GAUGE (NOMINAL)			
		30 mil (.75mm)	40 mil (1.0 mm)	60 mil (1.5 mm)	80 mil (2.0 mm)
Tensile Properties (Typical)	ASTM D638 Type IV Dumb-bell at 2 ipm.				
1. Tensile Strength at Break (Pounds/inch width)		45	55	70	85
2. Elongation at Break (Percent)		300	300	300	300
Tear Resistance Initiation Pounds. (Typical)	ASTM D1004 Die C	12	16	24	30
Puncture Resistance Pounds. (Typical)	FTMS 101 Method 2065	26	38	57	70
Multi-Axial Elongation	GR1-GM4	75	75	75	75

*(*Note: All values are typical test results.)*

SUPPLY SPECIFICATIONS

The following describes typical roll dimensions for Hyperlastic Textured

NOMINAL THICKNESS		WIDTH		LENGTH		AREA		ROLL WEIGHT	
mil	mm	ft.	m	ft.	m	ft.²	m²	lb.	kg.
30	0.75	22.5	6.86	840	256	18,900	1756	2141	971
40	1.0	22.5	6.86	500	152	11,250	1045	2676	1214
60	1.5	22.5	6.86	420	128	9,450	878	3147	1427
80	2.0	22.5	6.86	320	97	7,200	669	3083	1398

GUNDLINE HDT and HYPERPLASTIC TEXTURED are rolled on 6" I.D. hollow cores. Each roll is provided with 2 slings to aid handling on site. Dimensions and weights are approximate. Custom lengths available on request.

Gundle Lining Systems Inc.

Gundle®

19103 Gundle Road
Houston, Texas 77073 U.S.A.
Phone: (713) 443-8564
Toll Free: (800) 435-2008
Telex: 4620281 GundleHou
Fax: (713) 875-6010

These specifications are to be used only as a general guideline for use by engineers in formulating preliminary specifications, and should not be relied upon absent site-specific product testing; and Gundle assumes no responsibility for the improper reliance upon or misuse of such data. In addition, product design and specifications are subject to change without notice.

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PVC Data Sheet

OxyChem

GEOLAM™

TYPE 30/1120

GeoLam type 30/1120 provides superior puncture and tear resistance and dramatically increases the coefficient of friction properties not found in conventional lining materials. GeoLam is a Geocomposite of 30 mil OxyFlex® PVC Geomembrane and 6.0 osy Trevira® Spunbond type 1120. OxyFlex PVC, manufactured by Occidental Chemical Corporation, is a flexible geomembrane liner recognized for its use in Environmental Containment Systems. Hoechst Celanese Corporation's Trevira Spunbond, is a 100% continuous filament polyester nonwoven needlepunched engineering fabric. GeoLam type 30/1120 conforms to the property values listed in the table below:

GeoLam Property	Unit	Test Method	Typical Value
Basis weight	osy	ASTM D3776	35
Fabric Weight	osy	ASTM D3776	6.0
Thickness	mils	ASTM D1777	93
Tensile (MD/CD)	lbs/in.	ASTM D882	121/95
100% Modulus (MD/CD)	lbs/in.	ASTM D882	81/87
Elongation (MD/CD)	%	ASTM D882	570/545
Graves Tear (MD/CD)	lbs.	ASTM D1004 DIE C	29/22
Hydrostatic	psi	ASTM D751 METHOD A	400+

1/30/90

Occidental Chemical Corporation
Vinyls Division
5005 LBJ Freeway
Dallas, Texas 75244
214/404-3800

Trevira® Spunbond nonwoven engineering products are highly needled fabrics with excellent tensile properties, high filtration potential and outstanding permeability.

Trevira® Spunbond Type 11 products are 100% continuous filament polyester nonwoven needlepunched engineering fabrics. They deliver a combination of advantages unmatched by any other spunbonded geotextiles. They're resistant to freeze-thaw, soil chemicals and ultraviolet light exposure.

Trevira® Spunbond nonwoven engineering fabrics offer excellent performance where the requirement is tensile reinforcement, planar flow, filtration, or separation. They are ideal for roadways, railbeds, drainage systems, pondliners, retaining walls. And much more.

TYPICAL PHYSICAL PROPERTIES OF TREVIRA® TYPE 11 PRODUCTS

Fabric Property	Unit	Test Method	1112	1114	1120	1125	1135	1145	1155
Fabric Weight	oz/yd²	ASTM D-3776	3.5	4.2	6.0	7.5	10.5	13.5	16.5
Thickness, t	mils	ASTM D-1777	60	70	90	110	140	170	210
Grab Strength (MD/CD)[1]	lbs	ASTM D-4632	120/95	150/115	230/180	300/235	420/350	540/450	650/570
Grab Elongation (MD/CD)[1]	%	ASTM D-4632	65/75	75/85	75/85	75/85	75/80	80/80	85/85
Trapezoid Tear Strength (MD/CD)[1]	lbs	ASTM D-4533	50/40	55/50	80/75	105/95	140/125	180/165	225/200
Puncture Resistance	lbs	ASTM D-4833	55	65	95	115	155	185	225
Mullen Burst Strength	psi	ASTM D-3786	195	225	320	400	560	700	855
Water Flow Rate	gpm/ft²	ASTM D-4491	195	190	170	150	120	100	80
Permittivity, Ψ	sec⁻¹	ASTM D-4491	2.61	2.54	2.27	2.01	1.60	1.34	1.07
Permeability, k = Ψt	cm/sec	ASTM D-4491	.40	.45	.52	.56	.57	.58	.57
AOS	Sieve Size mm	ASTM D-4751	70-100 .210-.149	70-100 .210-.149	70-100 .210-.149	70-100 .210-.149	100-120 .149-.125	120-140 .125-.106	140-170 .106-.088
Standard Roll Widths[2]	ft		12.5 and 15.0						
Standard Roll Length[2]	ft		400	400	300	300	300	300	300

[1] MD = Machine Direction, CD = Cross Machine Direction. [2] Other width and length rolls are available upon request.

MINIMUM† PHYSICAL PROPERTIES OF TREVIRA® TYPE 11 PRODUCTS

Fabric Property	Unit	Test Method	1112	1114	1120	1125	1135	1145	1155
Fabric Weight	oz/yd²	ASTM D-3776	3.3	4.0	5.7	7.1	10.0	13.0	16.0
Thickness, t	mils	ASTM D-1777	50	55	75	95	125	150	185
Grab Strength	lbs	ASTM D-4632	80	100	160	210	305	390	500
Grab Elongation	%	ASTM D-4632	60	60	60	60	60	65	70
Trapezoid Tear Strength	lbs	ASTM D-4533	30	40	60	75	100	130	150
Puncture Resistance	lbs	ASTM D-4833	40	50	80	95	130	155	195
Mullen Burst Strength	psi	ASTM D-3786	170	190	275	360	510	640	780
Water Flow Rate	gpm/ft²	ASTM D-4491	155	150	130	110	80	60	40
Permittivity, Ψ	sec⁻¹	ASTM D-4491	2.07	2.01	1.74	1.47	1.07	0.80	0.53
Permeability, k = Ψt	cm/sec	ASTM D-4491	.26	.28	.33	.35	.34	.31	.25
AOS	Sieve Size mm	ASTM D-4751	50 .300	50 .300	70 .210	70 .210	70 .210	100 .149	100 .149

†These minimum values represent minimum test values determined from Q.C. testing on all lots produced in 1989. Certified "Minimum Average Roll Values" representing the industry standard of a 95 percent confidence level (i.e. mean less two standard deviations) may be higher than these values and are determined for each production lot. Please contact your Trevira® Distributor or Hoechst Celanese Corporation for additional information.

Engineering specifications*

Stevens Industrial Grade Containment Membrane

STEVENS
Elastomerics

Formulation: Formulation shall contain a minimum 45% by weight of Hypalon** 45 polymer as the sole elastomer. No other polymer is allowed.

Property	Test Method	Type .036	Type .045	Type .060
Gauge, nominal (mils)	--	36	45	60
Plies, reinforcing 10 x 10 1000d polyester	--	1	1	1
Thickness, minimum (mils)	ASTM D-751			
1. Overall	Optical Method (see	34	41	55
2. Over scrim	Appendix, Part 1)	11	11	11
Breaking strength - fabric, minimum (lbs)	ASTM D-751, Method A	200	250	300
Tear strength (pounds, minimum)				
1. Initial	ASTM D-751, Modified	80	90	100
2. After aging	(see Appendix, Part 2)	35	35	35
Low temperature flexibility (°F)	ASTM D-2136, 1/8 in. mandrel, 4 hrs - Pass	-40	-40	-40
Dimensional stability (each direction percent change maximum)	ASTM D-1204 212°F, 1 hr	2	2	4
Volatile loss, maximum, for 30 mil unsupported sheet (percent)	ASTM D-1203, Method A	0.5	0.5	0.5
Resistance to soil burial (maximum percent change from original values)				
a. 30-mil unsupported sheet	ASTM D-3083 (per			
1. Breaking strength	ASTM paragraph 9.5)	5	5	5
2. Elongation at break		20	20	20
3. Modulus at 100% elongation		20	20	20
b. Membrane fabric breaking strength	ASTM D-751, Method A	25	25	25
Hydrostatic resistance, minimum (psi)	ASTM D-751, Method A Procedure 1	250	250	300
Ply adhesion, each direction, minimum (lbs/in.)	ASTM D-413, Machine Method	8	8	8
	ASTM D-413, Modified Method (see Appendix, Part 3)	10	10	10
Water absorption, maximum, 30 mil unsupported sheet	ASTM D-471			
	14 days @ 70°F	1.5	1.5	1.5
	30 days @ 70°F	2.0	2.0	2.0
	120 days @ 70°F	2.0	2.0	2.0
	14 days @ 158°F	30.0	30.0	30.0
	30 days @ 158°F	30.0	30.0	30.0
	120 days @ 158°F	30.0	30.0	30.0

* *The product represented by this specification meets or exceeds all previous specifications published on Stevens Industrial Grade constainment membranes.*

***Hypalon is the registered trademark for DuPont's chlorosulfonated polyethylene (CSPE) synthetic rubber.*

JPS ELASTOMERICS CORP/Containment Membrane Division
395 Pleasant Street, Northampton, MA 01060
Tel: 413/586-8750 Fax: 413/584-6348 Telex: 402967JPSUD

Product Specifications

TYPICAL ROLL PROPERTIES

PROPERTY	TEST PROCEDURE	UNIT	POLYFELT 600	650	700	750	800	900	1000
Weight	ASTM D3776	oz/yd²	6.0	7.0	8.3	10.3	12.0	14.0	16.2
Thickness	ASTM D1777	mils	80	90	105	120	130	150	160
Grab Tensile	ASTM D4632	lbs	170	190	225	280	325	*380/320	*470/350
Grab Elongation	ASTM D4632	%	>50	>50	>50	>50	>60	*85/90	*90/95
Wide-Width Tensile	ASTM D4595	lb/in	75	85	100	120	135	145	150
Elongation at Break	ASTM D4595	%	>50	>50	>50	>55	>55	>80	>80
Puncture Resistance	ASTM D4833	lbs	85	100	115	130	150	155	170
Trapezoidal Tear	ASTM D4533	lbs	75	85	100	115	130	*150/135	*170/140
Mullen Burst	ASTM D3786	psi	255	295	345	425	450	470	490
Water Flow Rate	ASTM D4491	gpm/ft²	170	140	130	100	90	80	65
Permittivity	ASTM D4491	sec⁻¹	2.0	1.8	1.6	1.3	1.2	0.9	0.8
Permeability, Kv	ASTM D4491	cm/sec	0.4	0.4	0.4	0.4	0.4	0.35	0.35
Transmissivity at	ASTM D4716	gpm/ft (x10⁻²)							
0.3 psi			9.5	10.0	11.0	11.5	12.7	13.0	15.0
14.5 psi			4.0	5.0	7.0	7.0	7.0	7.0	7.0
29.0 psi			3.0	3.5	4.0	4.0	4.0	4.0	4.0
A.O.S.	ASTM D4751	sieve size	100-60	100-70	120-80	140-100	140-100	>140	>140
		mm	0.15-0.25	0.15-0.21	0.12-0.18	0.10-0.15	0.10-0.15	<0.10	<0.10
U.V. Resistance (500 hrs.)	ASTM D4355	% str. ret.	>85	>85	>85	>90	>90	>90	>90
pH Resistance			2-13	2-13	2-13	2-13	2-13	2-13	2-13

MINIMUM AVERAGE ROLL PROPERTIES

PROPERTY									
Grab Tensile	ASTM D4632	lbs	140	170	205	245	300	310	320
Grab Elongation	ASTM D4632	%	50	50	50	50	60	80	80
Puncture Resistance	ASTM D4833	lbs	70	85	95	115	130	135	140
Trapezoidal Tear	ASTM D4533	lbs	65	75	85	95	105	110	120
Mullen Burst	ASTM D3786	psi	220	260	300	380	400	425	450

*MD/CD

PACKAGING

ROLL							
Width, ft	15	15	15	14	13	10	10
Length, ft	360	360	360	300	300	300	300
Area, yd²	600	600	600	467	433	333	333
Weight, lbs	235	275	320	310	335	300	345

Nonstandard roll dimensions are available on request and subject to a minimum quantity. Mechanical properties based on standard roll width. 6/90

polyfelt

"Specified by Experts Worldwide"

Polyfelt's worldwide manufacturing, distribution and application engineering services are available to assist you with your geotextile project. Please contact our regional office nearest you.

North America

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200 Miller Sellers Drive
Post Office Box 727
Evergreen, Alabama 36401
Telephone: 205-578-4756
Customer Service: 800-225-4547
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Telefax: 205-578-4963

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Telefax: 404-668-2116

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Polyfelt France
F-93160 Noisy-le-Grand
Telephone: (1) 45-92-34-34
Telex: 232167 clf

Polyfelt Denmark
DK-1552 Copenhagen V,
Telephone: (01) 12-56-22
Telex: 16783 clag dk

Polyfelt Geosynthetics Sdn. Bhd.
No. 2, Jalan SS 21/62, Damansara Utama
47400 Petling Jaya,
Selangor Darul Ehaan, Malaysia
Telephone: 03-7191153, 7191157
Telefax: 03-7191117

polyfelt

Printed in USA 6/90

TERRA-TUFF
COMPOSITE GEOMEMBRANES
ENGINEERING SPECIFICATIONS

PROPERTY	TEST METHOD	TERRA-TUFF		
		801R	802R	802
Thickness, mils	ASTM D-1777	80	140	140
Tensile Strength, lbs.	ASTM D-1682	250	390	300
Tear Resistance, lbs.	ASTM D-4533	140	175	90
Puncture Resistance, lbs.	ASTM D-4833	300	380	220
Mullins Burst, psi	ASTM D-3786	500	500	N/A
Dimensional Stability (Max % change)	ASTM D-1204	2.0	2.0	3.5
Low Temperature Brittleness (1/8" mandrel, 4 hours, pass)	ASTM D-2136	-40°F	-40°F	-40°F
Transmissivity*, 8 oz. geotextile gal/min/ft. width X 10^{-3}	ASTM D-4716	12	12	12
Bonded seam strength, lbs/in.	ASTM D-4437	FTB(1)	FTB(1)	FTB(1)
Resistance to soil burial % strength retained	ASTM D-3083	95	95	95

*Transmissivity will vary with fabric weight. Geotextile is available in a 6 oz./square yard to 20 oz./square yard. Transmissivity values range from 12 to 50, respectively.

Terra-Tuff 801R, CSPE *reinforced membrane with an 8 oz. non-woven PET geotextile laminated to one side.

Terra-Tuff 802R, CSPE *reinforced membrane with an 8 oz. non-woven PET geotextile laminated on both sides.

Terra-Tuff 801, CSPE *unreinforced membrane with an 8 oz. non-woven PET geotextile laminated on one side.

(1) FTB - Film Tearing Bond; parent membrane fails before seam separation.

*Or equal polymer with approval of the engineer.

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OxyChem®

OXYFLEX® PVC GEOMEMBRANE LINER 40 MIL

›erty	Test Method	Required NSF 54*	Typical** Values
Gauge (nominal)	------	40	
Thickness, Mils (minimum)	ASTM D1593	38	39.5-40.5
Specific Gravity (minimum)	ASTM D792	1.20	1.280
Minimum Tensile Properties (each direction)	ASTM D882		
1. Breaking Factor (pounds/inch width)	Method A (1 inch wide)	92	MD 120 TD 115
2. Elongation at break (%)	Method A (2" jaw separation)	350	MD 500 TD 550
3. Modulus (force) at 100% elongation (pounds/inch width)	Method A	36	MD 60 TD 55
Tear Resistance (pounds, minimum)	ASTM D1004 Die C	10	MD 15.0 TD 16.0
Temperature, °F	ASTM D1790	-20	Pass
Dimensional Stability (each direction, % change maximum)	ASTM D1204 212°F, 15 min.	Less than 5%	Pass
Water Extraction (% loss maximum)	ASTM D3083 (as modified in Appendix A)	0.35	0.11
Volatile Loss (% loss maximum)	ASTM D1203 Method A	0.5	0.40
Resistance to Soil Burial (% change maximum in original value)	ASTM D3083 (as modified in Appendix A)		
1. Breaking factor		±5%	Pass
2. Elongation at break		±20%	Pass
3. Modulus at 100% elongation		±20%	Pass
Hydrostatic Resistance (pounds/sq. in. min.)	ASTM D751 Method A	110	157

Occidental Chemical Corporation
Polymers and Plastics
300 Berwyn Park—Suite 300
P. O. Box 1772, Berwyn, PA 19312
215/251-1000

*Proposed revision 4th draft December 1990

**OVER

K.S

ARMORFORM® UNIFORM SECTION MAT (USM)

TYPICAL DIMENSIONS, WEIGHTS AND VOLUMES

(Values shown are typical only, and will vary with field conditions.)

Uniform Section Size	Cord Spacing	Nominal Thickness	Weight/ Sq. Ft.	Coverage/ Cu. Yd. Concrete	Availability
3" USM	3" x 3"	3.0"	35 lbs.	97 ft.²	Inventory
4" USM	3" x 3"	4.0"	47 lbs.	73 ft.²	Inventory
6" USM	3" x 4"	6.0"	70 lbs.	49 ft.²	Inventory
8" USM	3" x 5"	8.0"	93 lbs.	36 ft.²	Special Order

PRODUCT DESCRIPTION

Uniform Section Mat (USM) is formed with a double-layer woven fabric, joined together by spacer cords and engineered exclusively to serve as a form for casting concrete erosion control linings. The fabric forms are positioned on the area to be protected, where they are filled with a pumpable fine aggregate concrete (structural grout).

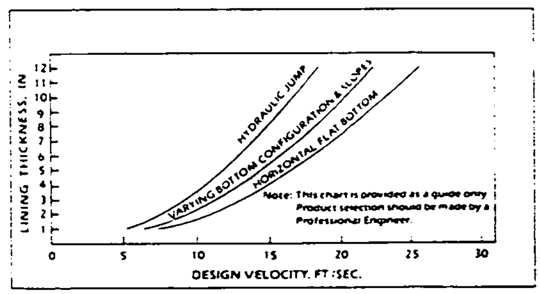
Uniform Section Mat fabric is woven from polypropylene slit film yarns, and designed with the required strength, stability, and filtration characteristics of a superior fabric form. The fabric forms are constructed with spacer cords on closely spaced centers to form a lining of required nominal thickness, bonded cobbled surface, and specified weight to provide strength and erosion protection. The design criterion for selection of lining thickness is the same as that used to determine the thickness of conventional concrete slope paving.

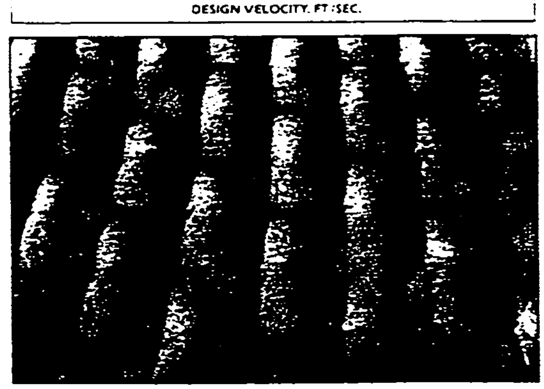
Relief of hydrostatic uplift pressure, caused by entrapped and ground water, may be provided by inserting plastic weep tubes through the mat at specified centers. When weep tubes are used, the lower end of the weep tube should be covered by filter fabric or the mat should be placed over filter fabric.

At Nicolon's fabrication facilities, Uniform Section Mat fabric in mill width rolls is factory fabricated into multiple mill width panels, designed to fit site dimensions and topography.

Panels are delivered to the job site where the installer assembles the panels into a continuous concrete forming system. Fabric forms contract as they are pumped with a structural grout. Allowance must be made for this contraction in estimating the quantity of fabric form required. Nicolon should be contacted to determine the appropriate contraction factors for your site conditions.

VELOCITY -VS- THICKNESS





FORTA®
FACT-DATA

CFP FIBER

1. PRODUCT NAME

FORTA® CFP

2. MANUFACTURER

FORTA Corporation, 100 FORTA Drive, Grove City, PA 16127-9990
1-800-245-0306 or 412-458-5221; FAX: 412-458-8331.

3. GENERAL DESCRIPTION

FORTA® CFP is a virgin homopolymer Collated Fibrillated Polypropylene (CFP) fibrous reinforcement additive for concrete. CFP FIBER is used to reduce plastic concrete shrinkage and to offer improvements to impact strength and durability.

4. APPLICATIONS

CFP FIBER is mainly used in cast-in-place concrete applications such as flatwork and slabs-on-grade where the major objective is control of early plastic shrinkage cracking. CFP FIBER is also used in various small precast concrete products. CFP FIBER will meet all criteria for specifications calling for minimum requirements of 1.5 pounds of virgin homopolymer polypropylene fiber per cubic yard of concrete.

5. DOSAGE RATES

Recommended dosage rate of FORTA® CFP is 1.5 pounds per cubic yard of concrete to perform as plastic shrinkage reinforcement. CFP FIBER is available in ¾" and 1½" lengths.

6. PHYSICAL PROPERTIES

Material	Virgin Homopolymer Polypropylene
Form	Collated Fibrillated Fiber
Specific Gravity	0.91
Tensile Strength	70,000 p.s.i. min.
Length	¾", 1½"
Color	White
Acid/Alkali Resistance	Inert

drainage and outfall structures, protection of levees and earthen dams. Project involvement has ranged in size from 1,000 to 1,700,000 square feet.

While the types of projects are varied the ARMORFORM process has been utilized successfully on each. From this we have gained considerable field experience which enables us to offer value engineered solutions using ARMORFORM which prove to be successful and cost effective.

8. TESTING

We propose to implement a testing program to compare the results of ARMORFORM grout with and without fibermesh reinforcing added to the mix. The purpose of this comparison will be to help determine through field experience and an independent testing lab, the most effective mix in terms of durability and cost.

We would like to use the following mix guidelines: (quantities/cubic yard)

#1) (8) sacks cement
2200# masons sand
60 gal water
5% air entrainment

#2) (8) sacks cement
2200# masons sand
1 1/2# fibermesh
60 gal water
5% air entrainment

Note these are guidelines and quantities may need to be adjusted in the field to achieve a pumpable mix.

For testing purposes half the ARMORFORM USM test section will be pumped with mix #1 and half with mix #2.

The strength of ARMORFORM grout is dependent upon the ability for the excess mixing water to be expelled through the water permeable fabric wall of the ARMORFORM fabric. This significantly lowers the water:cement ratio increasing the strength and rate of cure.

As a result of this, ARMORFORM grout cast into a conventional cylinder is not truly representative of the grout within the mat. To more accurately determine the insitu strength of the ARMORFORM, grout samples are pumped into a "test sock" fabricated from the ARMORFORM fabric having dimensions approximately 30" x 6" diameter. From the test sock 2" cubes are sawcut and tested; two cubes at seven (7) days and two cubes at (28) days for compressive strength.

We will cast one test sock per day of ARMORFORM pumping. We are also interested in establishing a correlation between ARMORFORM grout cast in a test sock and grout cast into a conventional cylinder where there is no provision for the reduction of the water:cement ratio.

We propose to cast two (2) conventional cylinders each from mix #1 and mix #2. Cylinders will be cast the first day of pumping for each mix with one cylinder tested at seven (7) days and one at (28) days for each respective mix.

Independent lab testing for this service will be performed by Century West Labs of Bend, Oregon.

DURA-FLEX VLDPE-A SPECIFICATIONS

POLY-FLEX
POLYETHYLENE GEOMEMBRANES

Typical Properties: 60 mil.

Property	Test Method	Test Results*
Thickness, mils, minimum	ASTM D 1593	54
Density (g/cc), maximum	ASTM D 1505	0.935
Melt Index (g/10 min., maximum)	ASTM D 1238	0.6
Carbon Black content (%)	ASTM D 1603	2 -3
Carbon Black Dispersion	ASTM D 3015	A-2
Tensile Properties	ASTM D 638	
1. Ultimate Tensile Strength (pounds/inch width)	Type IV specimen at 20 inches/minute	210
2. Ultimate Elongation (%)		1000
3. Modulus of Elasticity (secant modulus; pounds/square inch)		15,000
Tear Strength (lbs.)	ASTM D 1004 Die C	28
Puncture Resistance (lbs.)	**FTMS 101 C 2065	80
Low Temperature Brittleness	ASTM D 746	<-94° F
Dimensional Stability (% change max.)	ASTM D 1204 212° F, 15 min.	± 3
Resistance to Soil Burial (% change max. in orig. value)	ASTM D 3083 type IV specimen at 20 inches/minute	
A. Ultimate Tensile Strength		10
B. Ultimate Elongation		10
Environmental Stress Crack (hours)	ASTM D 1693 Condition C (modified NSF 54)	>2000
Field Seam Properties		
1. Shear Strength (pounds/inch), min.	ASTM D 3083 (modified NSF 54)	80 (or 20" elong.)
2. Peel Strength	ASTM D 413 (modified NSF 54)	FTB†

* All values, except when specified as minimum or maximum, represent average lot property values.
** Federal Test Method Standards.
† Film Tear Bond (FTB) is defined as failure of one of the sheets by tearing, instead of separating from the other sheet at the weld interface area (sheet fails before weld).

POLY-FLEX HDPE SPECIFICATIONS

POLY-FLEX
POLYETHYLENE GEOMEMBRANES

Typical Properties: 60 mil.

Property	Test Method	Test Results*
Thickness, mils, minimum	ASTM D 1593	54
Density (g/cc), minimum	ASTM D 1505	0.94
Melt Index (g/10 min., maximum)	ASTM D 1238	0.4
Carbon Black content (%)	ASTM D 1603	2 -3
Carbon Black Dispersion	ASTM D 3015	A-2
Tensile Properties	ASTM D 638	
1. Tensile Strength at Yield (pounds/inch width)	Type IV specimen at 2 inches/minute	150
2. Tensile Strength at Break (pounds/inch width)		250
3. Elongation at Yield (%)		13
4. Elongation at Break (%)		750
5. Modulus of Elasticity (1% secant; pounds/square inch)		90,000
Tear Strength (lbs.)	ASTM D 1004 Die C	47
Puncture Resistance (lbs.)	**FTMS 101 C 2031	260
Hydrostatic Resistance (lbs./square inch)	ASTM D 751	495
Low Temperature Brittleness	ASTM D 746	<-94° F
Dimensional Stability (% change max.)	ASTM D 1204 212° F, 15 min.	± 1
Volatile Loss (%)	ASTM D 1203	0.4
Resistance to Soil Burial (% change max. in orig. value)	ASTM D 3083 type IV specimen	
A. Tensile Strength at Yield & Break	at 2 inches/minute	10
B. Elongation at Yield & Break		10
Ozone Resistance	ASTM D 1149 7 days, 100 pphm 104° F, bent loop	no cracks
Environmental Stress Crack (hours)	ASTM D 1693 Condition C (modified NSF 54)	>2000
Water Absorption (% change max in original weight)	ASTM D 570	0.1
Coefficient of Linear Thermal Expansion (cm/cm · °c) x 10^{-4}	ASTM D 696	1.2
Moisture Vapor Transmission Rate (g/100 in² · day)	ASTM E 96 100° F, 100% relative humidity	0.020

* All values, except when specified as minimum or maximum, represent average lot property values.
** Federal Test Method Standards.

AMOCO

Amoco Fabrics and Fibers Company
Suite 550
900 Circle 75 Parkway
Atlanta, Georgia 30339
(404) 956-9025 - Telex 54-2963

August 30, 1993

Mr. Jay Swihart
Bureau of Reclamation
Materials Science Section
P.O. Box 25007, Mail Code D-3741
Denver, CO 80225

Dear Sir:

We wish to advise that **Amoco CEF Style 4512** meets the following minimum roll averages:

Property	Test Method	Minimum Roll Average Value	Typical Value
Weight	ASTM-D-3776	12.0	13.7
Grab Tensile, lbs	ASTM-D-4632	275	367
Grab Elongation, %	ASTM-D-4632	50	83
Mullen Burst, psi	ASTM-D-3786	650	993
Puncture, lbs	ASTM-D-4833	185	243
Trapezoidal Tear, lbs	ASTM-D-4533	115	166
UV Resistance, %SR	ASTM-D-4355	70	80
AOS, US Sieve #	ASTM-D-4751	100	100
Thickness, mils	ASTM-D-1777	130	192
Permittivity, 1/sec	ASTM-D-4491	0.9	1.2
gal/min/ft^2		60	83

Amoco Fabrics and Fibers Company manufactures Style 4512 in the USA. The values listed are a result of testing conducted in on-site laboratories. The typical values provided are for comparison purposes, and are representative of current production of this product.

Mike Clements
Sales Engineer
Civil Engineering Fabrics

Appendix D

Manufacturers' Data Sheets
North Unit Main Canal

Resin Technology Company

SPRAY SYSTEM
RT 2010 SERIES

TECHNICAL INFORMATION

DESCRIPTION

RT 2010 is a technologically advanced, sprayable polyurethane foam system.

RT 2010 is listed with Underwriters Laboratories, Inc., as a recognized component plastic (UL-94).

TYPICAL PHYSICAL PROPERTIES [Sprayed in Place][1]

	ASTM Method	RT 2010-1.6	RT 2010-2.0
Nominal Density	D 1622	1.6 pcf	2.0 pcf
Compressive Strength	D 1621	20 psi	30 psi
Tensile Strength	D 1623	32 psi	40 psi
Shear Strength	C 273	24 psi	35 psi
Closed Cell Content	D 1940	93%	93%
K Factor (Initial)[2]	C 518	0.11	0.11
K Factor (Aged)[2] (California)	C 177	0.14	0.14
Water Absorption (gm/cc)	D 2842	0.019	0.017
Water Vapor Transmission	C 355	2.0 perms	2.0 perms
Dimensional Stability	D 2126		
158°F/100% RH			
ΔV 1 Day		4%	3%
ΔV 7 Days		6%	5%
ΔV 28 Days		8%	8%
-10°F/Ambient RH			
ΔV 28 Days		± 1%	± 1%

1. This information is intended only as a guide for design purposes. The values shown are the average values obtained from sprayed laboratory samples. The test methods were performed per the ASTM Book of Standards.
2. K Factor varies depending on age and use conditions.

NOTE: THESE PRODUCTS ARE INTENDED FOR INDUSTRIAL USE ONLY

2270 CASTLE HARBOR PLACE • ONTARIO, CALIFORNIA 91761 • 714 947-7224 • FAX 714 923-9617

RTC

LIQUID COMPONENT PROPERTIES

	RT-2010-1.6	RT-2010-2.0
Viscosity/Specific Gravity at 70°F		
Component A (cps)	200/1.24	200/1.24
Component B (cps)	200±150cps/1.27	400±150cps/1.26
Mixing Ratio by Volume		
Component A	50	50
Component B	50	50

SURFACE BURNING CHARACTERISTICS*

ASTM E-84 (UL 723)*	
Flame Spread	25*
Fuel	5
Smoke	240

Sample spray applied at 2" thickness to ¼" Cement Asbestos Board.

***Note:** This numerical flame spread and all other data presented is not intended to reflect the hazards presented by this or any other material under actual fire conditions.

PROCESSING CHARACTERISTICS AND RECOMMENDATIONS

RECOMMENDED PROCESSING TEMPERATURES	Preheater	Hose
Component B	130-140°F	100-110°F
Component A	120-130°F	100-110°F

These temperatures are typical of those required to produce acceptable product using conventional Gusmer or Graco equipment. Environmental conditions may dictate the use of other temperature ranges. However, under no circumstances should a temperature of 140°F be exceeded. It is the responsibility of the applicator to determine the specific temperature settings to match the environmental conditions and his own equipment.

PROCESSING CHARACTERISTICS

Machine Mix at recommended temperatures*	Winter	Regular	Summer
Cream Time	1 sec.	2 sec.	3 sec.
Rise Time	5-6 sec.	8-10 sec.	14-16 sec.
Tack Free Time	On Rise	On Rise	On Rise
Cure Time	4 Hours	4 Hours	4 Hours

Reaction times are affected by the temperature of the substrate, the type of equipment and the temperature of the components.

*Sprayed through Gusmer Model H-II proportioner equipped with AR Gun with 100 pattern control tip at recommended processing temperatures.

RECOMMENDED SUBSTRATE TEMPERATURES

At time of application	RT 2010 Winter	RT 2010 Regular	RT 2010 Summer
Minimum	40°F	60°F	80°F
Maximum	80°F	120°F	140°F

For applications below 40°F, Resin Technology Company technical personnel should be consulted. At the lower end of the indicated temperature ranges, flash passes should be avoided.

SHELF LIFE

When stored in the original unopened container at 50°F-75°F, the shelf life of the components is six months. Temperatures above 75°F decrease the shelf life.

CAUTION: Polyurethane foam produced from these materials may present a fire hazard if exposed to fire or excessive heat (i.e. cutting torches). The use of polyurethane foam in interior applications on walls or ceilings presents an unreasonable fire risk unless protected by an approved fire resistant thermal barrier with a finish rating of not less than 15 minutes. A code definition of an approved "thermal barrier" is a material equal in fire resistance to ½" gypsum board. Each firm, person, or corporation engaged in the use, manufacture, production or application of the polyurethane foams produced from these resins should carefully examine his end use to determine any potential fire hazard associated with such product in a specific use and to utilize appropriate precautionary and safety measures. Consultation with building code officials and insurance agency personnel before application is recommended.

FREIGHT CLASSIFICATION

NOIBN Liquid Plastic Material

Technical Bulletin

Resin Technology Corporation

RT . 2020-5.0

DESCRIPTION

RT 2020-5.0 is a technically advanced, chloroflourocarbon-blown sprayable rigid polyurethane foam system.

APPLICATIONS

Tanks, Cold Storage, Transportation, Pipelines.

TYPICAL PHYSICAL PROPERTIES

PROPERTY	VALUE
Nominal Sprayed in Place Density (lbs/cu ft)	5.0
K factor initial (Btu/hr) (ft^2) (°F/in)	0.11
K factor aged (Btu/hr) (ft^2) (°F/in)	0.16
Closed Cell Content	90% min.
Compressive Strength (sprayed in place)	80-90 psig
Tensile Strength	80 psig
Shear Strength	50 psig
Water Absorption (gms/cc)	0.017
Water Vapor Transmission	2.0 perms

LIQUID COMPONENT PROPERTIES

PROPERTY	A	B
Color	dk brown	dk brown
Viscosity Brookfield (cps)	200	600 ± 150
Specific Gravity	1.24	1.10
Mixing Ratio by Volume	50	50

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REACTIVITY CHARACTERISTICS @ 75° F

Cream Time	1-3 sec.
Rise Time	8-12 sec
Tack Free Time	On Rise
Cure Time	4 hours

RECOMMENDED PROCESSING TEMPERATURES

	Preheater	Hose
Component A	130-140° F	90-120° F
Component B	130-140° F	90-120° F

These recommendations are only approximate. Processing conditions may vary depending on the type of equipment employed and environmental conditions.

SUBSTRATE TEMPERATURES

	Regular Grade
Minimum	65° F
Maximum	110° F

For applications below 65° F, Resin Technology Corporation technical personnel should be consulted. At the lower end of the indicated temperature ranges, flash passes should be avoided.

SHELF LIFE

When stored in original, unopened containers at 55-75° F, the shelf life of the components is a minimum of six months.

SAFETY PRECAUTIONS

Dermal exposure to the isocyanate component ("A" Component) may cuase sensitization, expecially if chronic exposure is encountered. Skin contact with this material should be flushed immediately with copious amounts of water followed by 30% Isopropyl alcohol solution. Skin exposure should be minimized by the use of fabric coveralls and gloves during spraying operations.

The use of a fresh air supply mask is recommended, expecially when spraying in confined areas. As minimum protection, organic vapor respirations are acceptable.

The "B" Component contains volatile chloroflourocarbons and may contain other components which may cause dermal sensitization. If rashes develop consult a physician immediately.

Eye contact with either material can result in severe damage to the cornea. Eye exposure should be flushed with copious amounts of water. Immediately contact trained medical personnel.

CAUTION: Polyurethane foam produced from these materials may present a fire hazard if exposed to fire or excessive heat (i.e. cutting torches). The use of polyurethane foam in interior applications on walls or ceilings presents an unreasonable fire risk unless protected by an approved fire resistant thermal barrier with a finish rating of not less than 15 minutes. A code definition of an approved "thermal barrier" is a material equal in fire resistance to ½" gypsum board. Each firm, person, or corporation engaged in the use, manufacture, production or application of the polyurethane foams produced from these resins should carefully examine his end use to determine any potential fire hazard associated with such product in a specific use and to utilize appropriate precautionary and safety measures.

FREIGHT CLASSIFICATION

NOIBN Liquid plastic material.

TECHNICAL DATA

FUTURA-FLEX 500

AROMATIC URETHANE ELASTOMER

PRODUCT DESCRIPTION

Futura-Flex 500 is a two component, hydrolytically stable aromatic urethane elastomer base coat designed for protection of polyurethane foam. The high solids and thixatropic nature of the coating, when properly mixed, permit application of a high build film on either horizontal or vertical surfaces. The cured film has an exceptional combination of high tensile strength and elongation, providing a tough and impact resistant protective membrane.

FEATURES

* Outstanding Toughness
* High Build/High Solids
* Excellent Chemical Resistance
* Convenient Mixing Ratio

TECHNICAL SPECIFICATIONS

Technical Data
The physical and performance properties of Futura-Flex 500 may be found in Tables 1 and 2 respectively.

Theoretical Coverage
Futura-Flex 500 Base - 1154 mil sq. ft./gal.

Recommended Thickness
20-30 mils (Total System)
1.8 gallons per square, depending on specification.

Number of Coats
Depending on specifications, 1-2 coats. When using Futura-Flex 550 as the finish, 1-2 coats of Futura-Flex 500 and one coat of Futura-Flex 550 is recommended.

Colors
Base Coat: Tan (Standard)
Intermediate Coat (Optional): Tan, Tinting Available

Compatibility with Other Elastomers
Obtain specific recommendations from Futura's Technical Department or Customer Service Representative.

Estimating Allowance
Allow 10-20% additional material for irregularity of surface and contingencies when estimating quantities.

ORDERING INFORMATION

Container Size
10 gallon kits (5 gallon pails)
110 gallon kits (55 gallon drums)
Approximate Weight
10 gallon kit -121 lbs.
110 gallon kit - 1331 lbs.
Freight Classification
Paint Compound NOIBN, Flammable Liquid - Red Label

Additional Information Available

* Chemical Tests
* Specifications
  Roofing
  Hot Tanks
* Current UL Classification Listing
* Warranty
* Distributor/Sales Office Locations

TABLE 1: TYPICAL PROPERTIES (WET)

TEST	SPECIFICATIONS	RESULTS
Weight (#/gal) Component A Component B	ASTM D-1475	 9.2 ± 0.5 13.0 ± 0.5
Mixing Ratio:	A:B - By Volume	1:1
Solids (mixed): by Weight by Volume	ASTM D-1353 Calculated	 86% ± 2 72% ± 1
Flash Point	Pensky Martens Closed Cup	80°F
Storage Stability Component A Component B	45°F-80°F	 6 months 1 year

TABLE 2: TYPICAL PERFORMANCE PROPERTIES OF CURED MEMBRANE

PHYSICAL PROPERTIES	TEST METHOD	RESULTS
Tensile	ASTM D 412 (Die C at 20 in. per min.)	1600 PSI ± 25
Elongation at 75°F	ASTM D 412 (Die C at 20 in. per min.)	450% ± 25
Tear Resistance	ASTM 624 (Die C at 20 in. per min.)	290 PLI ± 25
Permeability	ASTM E 96, Procedure B (at 20 mils)	0.65 U.S. Perm 0.41 Metric Perm .013 Perm Inches
Hardness	ASTM D 2240, Shore A	80 ± 5
Accelerated Weathering	ASTM G-53-77 - Q-UV D-822 Atlas Carbon Arc	This is a base coat and is designed to be used with a topcoat system.
Water Absorption	ASTM D 471 (3 Days at 75°F)	1.5% Maximum
Low Temperature Flexibility	ASTM D-2136 180° bend at minus 50°F	Passes
High Temperature Resistance	D-573 Continuous Intermittent	200°F (93°C) 225°F (107°C)
Heat Aging (Accelerated)	ASTM D 573 (30 days at 185°F)	No significant change in physical properties
Abrasion Resistance	ASTM C 501 (CS-17 Wheel, 1000 rev./1000 gram weight.)	29 mg ± 2

APPLICATION INSTRUCTIONS

Method

Futura-Flex 500 is designed for airless or conventional spray equipment. A brush or roller is acceptable for touch-up. See Futura's Plural Component Equipment Guide for further information. (EQ 120) Using a .025-.035 orfice spray tip at a 60°-80° fan angle.

Spraying

Futura-Flex 500 is formulated to spray directly without thinning or heating. A spray pressure of 2800-3000 PSI and a 60° to 80° wide angle spray tip .025 to .035 will provide good atomization and a uniform application.

Thinning

None normally required. However, a change in viscosity is possible in unopened containers. For these instances, use up to 10% #50 Urethane Thinner.

Pot Life (Temperature/Time)

Temperature	Pot Life
55°F	2 1/2 - 5 hrs.
75°F	1 1/2 - 2 1/2 hrs.
95°F	3/4 - 1 1/2 hrs.
115°F	1/2 - 3/4 hr.

Application Temperatures

	Material	Surface
Minimum	45°F	45°F
Maximum	110°F	160°F

Batch Mixing

Do not mix more material than can be used within the potlife of the material.

NOTE: Dark hoses on dark roofs absorb tremendous amounts of heat. Do not leave mixed material in fluid lines for more than a few minutes when spraying is stopped.

Recoating

The recommended recoat schedule for Futura-Flex 500 is as soon as cured but within 72 hours.

Clean-Up

Equipment - For best results, use Thinner #50, a mixture of Xylol and MEK (50/50), or Xylol.

Cure Schedule

The cure time will vary depending on temperature and humidity. Use this information as a general guide:

Temperature	Dry Time	Complete Cure
45°F	18-24 hrs.	5 days
75°F	6-8 hrs.	3 days
90°F	4-6 hrs.	2 days

GENERAL SAFETY, TOXICITY AND HEALTH DATA

A Material Safety Data Sheet is available for this coating material and accompanies product shipments. Any individual who may come in contact with this product should read and understand the Material Safety Data Sheet.

RDS500 920625

FUTURA COATINGS, INC., 9200 LATTY AVE., HAZELWOOD (ST. LOUIS), MO 63042, (314) 521-4100, FAX # (314) 521-7255

FUTURA COATINGS INC. **TECHNICAL DATA**

FUTURA-FLEX 550

ALIPHATIC URETHANE ELASTOMER

PRODUCT DESCRIPTION

FUTURA-FLEX 550 is a two component, fire resistant aliphatic urethane which exhibits long-term color and gloss retention. It is a premium grade elastomeric coating which is recommended when an aesthetically appealing and exceptionally durable exterior finish is desired.

FUTURA-FLEX 550 is primarily designed for use over polyurethane foam as a finish coat but may also be used over concrete, masonry, wood and metal substrates where a flexible, high gloss and color retentive coating is required.

FEATURES

* Superior Color & Gloss Stability
* Super Tough
* Excellent Weatherability
* Fire Retardant
* High Solids
* Excellent Chemical Resistance
* Convenient Mixing Ratio

TECHNICAL SPECIFICATIONS

Theoretical Coverage
1,042 mil sq. ft./gal.
Recommended Thickness
10-15 mils over Futura Urethane Base Coat
Practical Coverage
One gallon per square yields 10 dry mils
Compatibility with Other Elastomers
FUTURA-FLEX 550 may be used as a finish coat for almost all of Futura's line of urethane and butyl rubber coatings. (Obtain specific recommendations from Futura's Technical Services Department).
Estimating Allowance
Allow 10-20% additional material for irregularity of surface and contingencies when estimating quantities.

ORDERING INFORMATION

Container Size
10 gallon kits (5 gallon pails)
110 gallon kits (55 gallon drums)
Approximate Weight
10 gallon kit -122 lbs.
110 gallon kit - 1342 lbs.
Freight Classification
Paint Compound NOIBN, Flammable Liquids

ADDITIONAL INFORMATION

* Chemical Tests
* Specifications
  Roofing
  Hot Tanks
  Cold Tanks
  Coolers & Freezers
* Current UL Classification Listing
* Warranty
* Distributor and Sales Office Locations

APPLICATION INFORMATION

Method
FUTURA-FLEX 550 is designed for airless or conventional spray equipment. A brush or roller is acceptable for touch-up. See Futura's Plural Component Equipment Guide for further information.
Pot Life
55°F - 2 1/2 to 5 hours
75°F - 1 1/2 to 2 1/2 hours
95°F - 3/4 to 1 1/2 hours
115°F - 1/2 to 3/4 hours

TABLE 1: TYPICAL PROPERTIES (WET)

TEST	SPECIFICATIONS	RESULTS
Weight (#/gal)	ASTM D-1475	
Component A		8.5 ± 0.5
Component B		14.0 ± 0.5
Mixing Ratio:	A:B - By Volume	1:1
Solids (mixed):		
by Weight	ASTM D-1353	75% ± 2
by Volume	Calculated	65% ± 1
Flash Point	Pensky Martins Closed Cup	85°F
Storage Stability	40°F to 100°F	
Component A		1 year
Component B		1 year

TABLE 2: TYPICAL PERFORMANCE PROPERTIES OF CURED MEMBRANE

PHYSICAL PROPERTIES	TEST METHOD	RESULTS
Tensile	ASTM D 412	2700 PSI ± 50
Elongation at 75°F (23.9°C)	ASTM D 412	275% ± 25
Tear Resistance	ASTM 624	275 PLI±25
Permeability	ASTM E 96, Procedure B	0.48 U.S. Perms 0.31 Metric Perms 0.01 Perm Inches
Hardness	ASTM D 2240, Shore A	75 ± 5
Accelerated Weathering Q-UV Accel. Weathering Tester (6000 Hours)	ASTM G 53-77	Futura-Flex 550 retained an excellent appearance after Q-UV, Carbon Arc, and EMMAQUA. There was no evidence of chalking, checking, delamination or loss of flexibility.
Atlas Carbon Arc Weatherometer (6000 Hours)	ASTM D 822 (Continuous UV and water spray cycle)	
EMMAQUA UV Radiation (2,000,000 Langleys)	ASTM E 838	
Water Absorption	ASTM D 471 3 days at 75°F	1.5% Maximum
Accelerated Heat Aging	ASTM D 573 30 days	No real change in physical properties
Low Temperature Flexibility	ASTM D 2136 180° bend	Passes
High Temperature Resistance	ASTM D 573 Continuous Intermittent	 200°F 225°F
Abrasion Resistance	ASTM C 501 CS-17 wheel 1000 rev./1000 gram weight	33 mg ± 2

APPLICATION INFORMATION (continued)

Batch Mixing: Thoroughly power agitate materials until completely mixed. Do not mix more material than can be used within the pot life of the material.

Storage: Store materials in a dry environment with a minimum temperature of 40°F and a maximum temperature of 100°F. If component 'A' is opened, purge with nitrogen and reseal in smaller containers to eliminate polymerization in the can.

Thinning: Do not thin components when using plural component equipment. For premix applications, while thinning is not normally required, use up to 10% of No. 50 Urethane Thinner to the mixed components for change of viscosity in opened containers.

Application Temperatures:

	Material	Surface
Minimum	45°F	45°F
Maximum	110°F	160°F

Clean Up: Equipment-For best results, use Thinner No. 50. A mixture of XYLOL and MEK (50/50) is acceptable.

Cure Schedule

The cure time will vary depending on temperature and humidity. Use this information as a general guide:

Temperature	Dry Time	Complete Cure
35°F	24-48 hrs.	5 days
50°F	18-24 hrs.	4 days
75°F	6-8 hrs.	3 days
90°F	4-6 hrs.	2 days

APPLICATION GUIDELINES:

1) DO NOT apply over wet substrates or when inclement weather is imminent.
2) DO NOT apply without adequate air exchange and ventilation in enclosed areas.
3) CAUTION: Before use, system should be purged to eliminate all solvents.

GENERAL SAFETY, TOXICITY AND HEALTH DATA

Material Safety Data Sheets are available on this coating material. Any individual who may come in contact with these products should read and understand the Material Safety Data Sheet.

920630 RDS550

FUTURA COATINGS, INC., 9200 LATTY AVE., HAZELWOOD (ST. LOUIS), MO 63042, (314) 521-4100, FAX # (314) 521-7255

FUTURA COATINGS INC

TECHNICAL DATA

GEOTHANE 520/5020

MODIFIED URETHANE MEMBRANE COATING

PRODUCT DESCRIPTION

Geothane 520 is a spray-applied, 100% solids, two component hydrocarbon modified urethane. It forms a tough, highly elastic membrane with excellent water and chemical resistance. It is designed for use with or without a geotextile fabric. The monolithic, seamless lining achieved by spray application offers an unparalleled level of dependability. These properties make Geothane 520 the lining of choice in a broad range of containment applications.

Geothane 5020 is a 100% solids, fast-curing, plural component, hydrocarbon, modified urethane having similar physical properties. The primary difference between the two materials is the broader temperature range in which Geothane 5020 can be applied and its instant cure properties.

RECOMMENDED USES

Pond and Lagoon Liners: Both Geothane 520 and Geothane 5020 may be ideally used as a chemical resistant, waterproofing membrane for earthen containment areas demanding high performance. They can be used in conjunction with a geotextile fabric in settling ponds, neutralization basins, waste lagoons and tailing ponds. Both materials have good UV resistance for long-term weathering on exterior exposure.

Tank Lining Membrane: Both Geothane 520 and Geothane 5020 may be used as a high build, elastomeric lining system for steel and concrete tanks, reservoirs, dikes, and their ancillary pipe trenches and sumps. The outstanding elongation of these two products permits them to bridge most hairline cracks that may develop in concrete basins or tanks. Their inherent flexibility and chemical resistance is retained in both high and low temperature service.

Environmental Cover: Geothane 520 and Geothane 5020 when sprayed over a geotextile fabric form an effective environmental cover to encapsulate contaminated soil or waste in landfill applications. The tough, flexible membrane prevents run off and controls wind erosion preventing accidental contamination of adjacent areas.

Repair Material For Existing Pond Liners: Geothane 520 and Geothane 5020 are excellent materials to repair torn or failed seams in plastic sheet linings. On a larger scale, they may be used to replace major segments of imbrittled existing sheet liners offering a long-term solution to eliminate potential leak problems.

FEATURES

Seamless: Both Geothane 520 and Geothane 5020 form monolithic, seamless membranes when applied. The elimination of seams by these liquid applied systems removes the greatest potential failure point of lining systems. This allows them to provide unparalleled levels of dependability and performance.

Convenient Application Characteristics: Geothane 520 may either be batch mixed or sprayed through plural component spray equipment while Geothane 5020 is designed only for plural component spray equipment which offers a greater ease of handling.

Wide Range Of Application Temperatures: Geothane 520 may be safely applied at temperatures as low as 45°F while Geothane 5020 may be applied as low as 35°F. This substantially extends the application season through a greater portion of the year.

High Build Properties: Geothane 520 is designed for 30 to 50 mil applications in single operations while Geothane 5020 may be built to thicknesses of up to 100 mils in a single operation. Both allow rapid installations while maintaining absolute economy.

Low Volatile Organic Content: Both Geothane 520 and Geothane 5020 contain no volatile organic compounds and therefore meet all existing emission guidelines.

Meets RCRA Guidelines: Both Geothane 520 and Geothane 5020 meet the guidelines established by the Resource Conservation and Recovery Act for hazardous materials containment.

TECHNICAL SPECIFICATIONS

Recommended Thickness: 30 to 100 mils DFT depending on service exclusive of any geotextile fabric used in conjunction with the materials.
Theoretical Coverage: 1600 mil square feet/gallon
Number of Coats: Normally one
Color: Black only
Geotextile Fabric Compatibility: Consult Futura Coatings for specific recommendations.
Primer: Due to the variety of substrates with which these products may be used, consult **Application Section** of this data sheet for specific recommendations.
Compatibility With Other Coatings: Do not use these products over other paint or coating materials without a specific recommendation from Futura Coatings.

ORDERING INFORMATION

Availability: 10 gallon kits
110 gallon kits

Approximate Shipping Weight: Geothane 520, 9.8 lbs./gal.
Geothane 5020, 10.2 lbs./gal.

Freight Classification: Coatings Solution Non-Flammable Liquid UN1139

OTHER INFORMATION AVAILABLE

* Specification "Geothane, Geomembrane Containment Systems and Tank Lining Specifications"
* General Chemical Resistance Charts
* Plural Component Equipment Guide EQ-02

TYPICAL WET PROPERTIES

TEST	SPECIFICATION	RESULTS 520	RESULTS 5020
Weight (#/gallon) (Mixed)	ASTM D-1475	8.8 ± .5	9.1 ± .5
Solids By Weight	ASTM D-1353	100%	100%
By Volume	Calculated	100%	100%
VOC	Calculated	0	0
Viscosity	Brookfield LV4/60RPM		
	Component A*	1700 CPS	1550 CPS
	Component B*	2000 CPS	2100 CPS
Flash Point	PMCC	300°F	300°F
Shelf Life	60°F to 90°F		
	Component A	9 mos	9 mos
	Component B	1 year	1 year

* Typical Value

APPLICATION INFORMATION

Surface Preparation:

Concrete: Apply over clean and dry surfaces that have been properly prepared. Standard concrete requires 28 days cure. Accelerated materials may be overcoated in as little as 15 days. In applications where high specific adhesion is a requirement, acid etch or abrasive blast to remove curing agents, form release agents or other laitances. In addition, priming of the concrete surface will be required. Primers must be topcoated within their specified recoat time.

Steel: Apply only over surfaces that have been abrasive blasted to white metal in accordance with SSPC SP5-63 white metals with a 2.5 mil profile. All surfaces must then be primed with the appropriate metal primer and the primer will be topcoated within their specified recoat time.

Earthen Base And Environmental Cover: They require a Geotextile Fabric System. Consult Futura's **"Geothane, Geomembrane Containment Systems and Tank Lining Specification"** for details.

Plastic Sheet Liners: Consult Futura Coatings for recommendations.

TYPICAL PHYSICAL PROPERTIES OF CURED MATERIALS

PHYSICAL PROPERTY	TEST METHOD		VALUE 520	VALUE 5020
Tensile Strength	ASTM D-412 Dye C 20 in/min		(N) 800 PSI ± 100 (R) 1000 PSI ± 100 *	1500 PSI ± 100 2400 PSI ± 100 *
Elongation at 75°F	ASTM D-412 Dye C 20 in/min		(N) 300% ± 25 (R) 40-60% *	320% ± 25 40-60% *
Tear Resistance	ASTM D-1938 Split Tear		(N) 60 ± 5 PLI (R) 500 - 800 PLI *	85 ± 5 PLI 500 - 800 PLI *
Low Temperature Flexibility	ASTM D-1737 1/2" mandrel bend at minus 55°F (-47°C)		Passes	Passes
High Temperature Resistance	ASTM D-573	Continuous Intermittent	(N) 200°F (N) 250°F	200°F 275°F
Hardness	ASTM D-2240 Shore A		(N) 65 ± 5	65 ± 5
Weatherability	ASTM G-53 (QUV Weathering)		After 2000 hours of exposure, there was no evidence of checking, cracking, or loss of flexibility.	

(N) = NON-REINFORCED MEMBRANE (R) = REINFORCED MEMBRANE
* = THE PROPERTY VALUE WILL VARY DEPENDING ON THE TYPE AND WEIGHT OF FABRIC USED.

APPLICATION INFORMATION (cont)

Method:

Geothane 520 and Geothane 5020 may be applied by the following methods:

Geothane 520: High pressure plural component airless spray
High pressure modified plural component airless spray
High pressure airless spray (batch mix)

Geothane 5020: High pressure plural component airless spray only

For detailed information on application equipment and spray parameters see **Futura Coatings Plural Component Equipment Guide EQ-02.**

Recommended Primer:

Concrete or masonry with high specific adhesion requirements: Futura-Bond 307 or Futura-Bond 502
Concrete or masonry with standard adhesion requirements: None

Steel immersion or non-immersion: Futura-Bond 300 or Futura-Bond 304.

Plastic sheet liners: Consult Futura Coatings Inc. for specific recommendations

Mixing:

Prior to using the individual components of Geothane 520 and Geothane 5020, they should be thoroughly agitated. Extreme care should be taken not to cross contaminate the individual components with the mixing equipment.

Batch Mixing Geothane 520: Mix as received in kit form or if less than one full kit is to be used, mix one part of Component A with one part of Component B by volume.

Note: Geothane 5020 may not be used as a batch mix or pre-mix material.

Pot life:

Geothane 520, 40 minutes at 75°F. If pre-mix method of application is used, do not mix more material than can be used with in the effective pot life of the material. Note: Higher temperatures reduce effective pot life.

Geothane 5020 is a fast-cure material and cannot be premixed.

Thinning:

Do not thin these materials for application.

REQUIRED TEMPERATURE OF APPLICATION

Geothane 520:
Material temperature: 65°F to 95°F
Air and surface temperature: 45°F and rising

Geothane 5020:
Material temperature: 65°F minimum
Air and surface temperature: 35°F and rising

Recoat and Cure Schedule:

Recoat: Geothane 520 - 4 to 6 hours or as soon as dry and within 48 hours at 75°F.
Geothane 5020 - 5 to 10 minutes or as soon as dry and within 24 hours at 75°F.

Cure Schedule Before Service: Geothane 520 3-5 days at 75°F
Geothane 5020 1-2 days at 75°F

Cleanup:

Standard high pressure airless equipment - Use Xylol or No. 50 Thinner
Plural component airless equipment - Consult **Futura Coatings Plural Component Equipment Guide EQ-02** for information.

GENERAL SAFETY, TOXICITY AND HEALTH DATA

Material Safety Data Sheets are available on this coating material. Any individual who may come in contact with these products should read and understand the Material Safety Data Sheet.

WARNING: Contact with skin or inhalation of vapors may cause an allergic reaction. Avoid eye contact of the liquid or spray mist.

Eye Protection: Safety glasses, splash goggles, or face shield are recommended.

Skin Protection: Chemical resistant gloves are recommended. Cover as much of the exposed skin area as possible with appropriate clothing.

Respiratory Protection: Use a respirator approved for isocyanates and/or organic vapors. Consider the application and environmental concentrations in deciding if additional protective measures are necessary.

Ingestion: Do not take internally. It is believed ingestion of TDI, MDI or polymeric isocyanates would not be fatal to humans but may cause inflammation of mouth and stomach tissue.

Rep: Futura-Flex 520 860303
Futura-Thane 5020 1/87

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TIETEX CORPORATION

TIETEX

Dan Bell
Product Manager

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Spartanburg, SC 29304
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TEST REPORT AVERAGES

FOR STYLE T-249

Tensile Strength 1" Jaws		Ball	Trapezoid Tears		Tongue Tears		Random Tumble	Seam Slippage		Percentage Elongation				
Warp	Filling	Burst	Warp	Filling	Warp	Filling	Pilling	Warp	Filling	Warp	Filling	Oil	Water	Spray
77.0	143.0	142.0	11.1	44.5	7.2	10.4	Class 4.5	41.0 TB	41.0 TB	27.4%	54.0%	7	20/80	Class 75

The figures above are average typical properties and are not to be considered guaranteed minimums.

WDB/gg
TEST/BELL.293

RUFON™

NONWOVEN PHILLIPS 66 FABRIC

PHILLIPS FIBERS CORPORATION
A SUBSIDIARY OF PHILLIPS PETROLEUM COMPANY

*Trademark Phillips Petroleum Company

END USE		COLD APPLIED SYSTEMS	
Fabric Type		E6N	
Color		White	
Average Weight		6.0	oz/yd^2
Tensile Strength (Grab)	Length	150	lb.
	Width	175	lb.
Stretch	Length	65	%
	Width	85	%
Tear Strength (Trapezoid)	Length	35	lb.
	Width	55	lb.
Burst (Mullen)		115	psi

Fiber Content Polyester
Binder Type None

STANDARD PUT UP

Each roll:
Width: 36
Length: 375 ft.
Area: 10 sq. Net or 11.25 Sqs./roll
Weight: Appox. wt. 55#
Packaged in black polyethylene bags

Effect of Novocrimp Fibers on the Physical Properties of Concrete

The addition of Novocrimp steel fiber improves the behavior and physical properties of concrete as follows:

- Increased fatigue endurance
- Increased shear strength
- Increased flexural strength
- Increased impact resistance
- Increased toughness
- Increased crack and spall resistance

In order to achieve the desired results, a properly designed concrete matrix is very important.

This Table demonstrates the positive effect of steel fibers over plain concrete.

Table I

Physical Property of Concrete	Effect of Novocrimp Steel Fibers
Modulus of Rupture	1.5-3.0 x plain concrete
Shear Strength	1.25-2.0 x plain concrete
Torsional Strength	1.5-2.0 x plain concrete
Energy Absorption	10-15 x plain concrete
Fatigue Strength	1.6 x plain concrete
Abrasion Resistance	1.2 x plain concrete
Cavitation/ Erosion Resistance	1.2 x plain concrete
Corrosion Resistance	Numerous tests and practical applications, including bridge decks subjected to heavy deicing salt and sea walls in North Atlantic, indicate the superior performance of SFRC compared to plain and conventionally reinforced concrete.

*Note: *The concrete mix design and the length and dosage of Novocrimp steel fibres account for the range of results.*

This Table provides typical concentrations of Novocrimp steel fibers for various applications.

Table 2

Fiber Length in. (mm)	Application	Fiber Content lb/c.y.	(kg/m3)
0.5 (12)*	SFR Grouts	45-65	25-40
1.0 (25)	Dry Mix Shotcrete Thin precast members & overlays	85-120 45-65	70-50 25-40
1.5 (38)	Wet mix shotcrete Thin precast members & overlays	85-120 45-65	50-70 25-40
2.0 (50)	Toppings on steel decks/precast	15-25	10-15
2.5 (63)*	Industrial or Commercial Floors Airports Roads Bridge Decks Precast Members	25-75 65-100 45-100 75-135 35-100	15-45 40-60 25-60 45-80 20-60
*special order			

Steel Fiber Reinforced Concrete is an extremely durable and tough material.

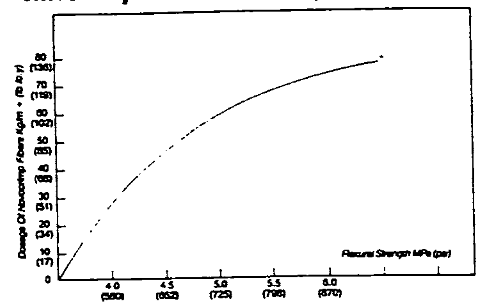


Figure 1. Flexural Strength of SFRC Concrete. This illustrates the almost linear increase in the flexural strength of Novocrimp fiber reinforced concrete with increased fiber dosage.

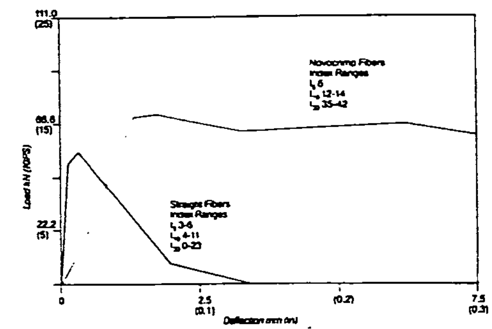


Figure 2. Post Crack Behavior of Novocrimp Fiber. This demonstrates the load carrying capabilities of Novocrimp fiber reinforced concrete even after the first crack occurs.

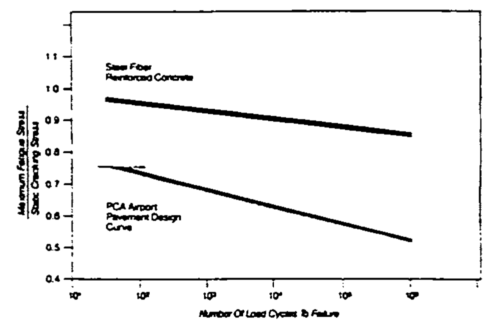


Figure 3. Fatigue Stress. This illustrates the great improvement in fatigue endurance provided by Novocrimp fibers.

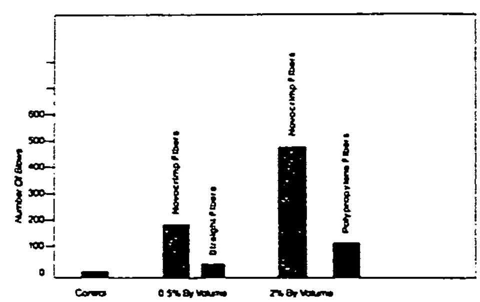


Figure 4. Impact Resistance of Novocrimp Fibers. This details the results of tests conducted with various concrete mixes to determine the number of blows required to break the concrete.

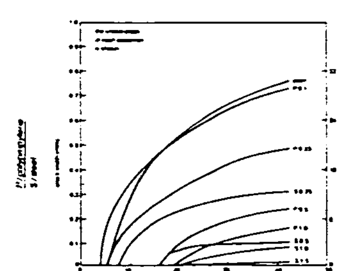


Figure 5. Crack Width Versus Time for Various Volume Percentages of Steel Fibers. The graph displays the superior crack controlling mechanism provided by steel fibers versus polypropylene fibers.

FI-CON* POLYPROPYLENE FIBER (PCC ADDITIVE) BY PHILLIPS

FI-CON™ is specifically engineered by Phillips for reducing shrinkage cracks in portland cement concrete.

FI-CON™ is added to the concrete mix and is a simple, effective, and economical method of reducing the formation of plastic settlement in concrete.

FI-CON™ is made of tough polypropylene—known and proven for the outstanding performance characteristics it adds to pcc..

Major benefits **FI-CON™** brings to pcc include:

- Reduces shrinkage cracks
- Reduces permeability to moisture and chlorides
- Increases compressive strength, flexural strength, and splitting tensile strength
- Increases fatigue resilience
- Greater impact resistance

Properties of FI-CON™

Diameter (denier)	0.0019" (15 denier)
Length	3/4"
Specific gravity	0.90-0.91
Tensile strength (tenacity)	>40,000 psi
Elongation	>60%
Moisture regain (70°F, 65% RH)	less than 0.1%
Material	polypropylene
Effect of extreme cold	polypropylene remains flexible at −100°F

FI-CON™ polypropylene fibers are inert, water insoluble, and remain dimensionally stable with changes in humidity. They are durable and offer excellent chemical, weather, and abrasion resistance. Polypropylene is superior to polyester in high alkaline conditions such as those experienced in pcc. Additionally, polypropylene is highly soil and stain resistant and resistant to bacterial attack (does not support growth of mildew or fungi).

INFORMATION

FI-CON™ is manufactured by Phillips Fibers Corporation, producer of Marvess® (polypropylene) olefin fiber and yarn for a wide range of consumer and industrial applications and manufacturer of nonwoven fabrics and geotextiles. For further information contact Phillips Fibers Corporation, P.O. Box 66, Greenville, SC 29602, attention Engineered Products Marketing. Call 803-242-6600 or 800-845-5737.

PHILLIPS 66

PHILLIPS FIBERS CORPORATION
A SUBSIDIARY OF PHILLIPS 66 COMPANY
ENGINEERED PRODUCTS MARKETING
P.O. BOX 66, GREENVILLE, SC 29602 (803) 242-6600

Harbourite S/G Types:

Harbourite 300
[Fibrillated Fiber 1/2" length]

Harbourite 320
[Fibrillated Fiber 3/4" length]

Shotcreting S/G Concrete on Quarry Wall

Product Data:

100 % Virgin Polypropylene Material

Alkaline Proof

Specific Gravity 0.91

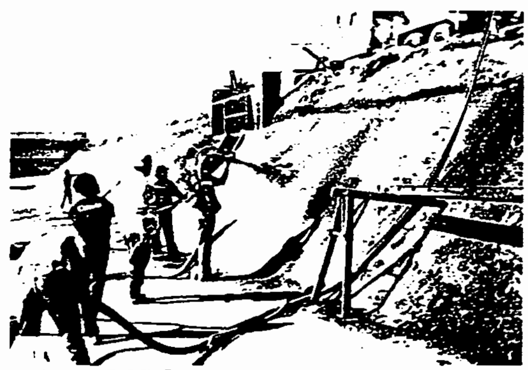
Ignition Temp 1,100° F (593C)

Absorption NIL

Tensile Strength 80-110 ksi (.56-77 kN/mm2)

Modulus (Youngs) 103 ksi 0.5 (3.5 kN/mm2)

Concrete Gunite Dome Toughened with Harbourite S/G



Arizona DOT Shotcrete Project Reinforced with Harbourite

Harbourite is warranted to be free of defects and to meet all quality control standards set by the manufacturer. Fibermesh Company has no control over the design, manufacture, or testing of the concrete products which incorporate our materials. Therefore, Fibermesh Company assumes no responsibility for the end products or uses made of our materials. The manufacturer or processor is responsible for testing its products to establish the physical properties thereof. It is the manufacturer's or processor's responsibility to certify compliance of his product, including any formulation which may include our materials with applicable design and physical testing

Fibermesh Company . Worldwide Headquarters . 4019 Industry Drive . Chattanooga, TN 37416

A Division of Synthetic Industries

H-103 888

Ensure materials and surrounding air temperature are maintained at a minimum 35 degrees F during and 3 days after placement of shotcrete.

B. During freezing weather provide cover to maintain shotcrete at or above 35 degrees F.

PART II -- PRODUCTS

2.01 Materials

A. Cement: ASTM C150 Type I or II.

B. Sand and Gravel: ASTM C-33

C. Water: Potable

D. Additives: Water reducing and Air Entraining only per ASTM

E. Reinforcement: Steel Fibers per ASTM C1116 and ASTM A820 Type I

2.02 Mix Proportions

A. Conform to following requirements:

1. Compressive strength (28 days) - 2500 PSI

2. Cementitious Materials - 610 pounds per cubic yard minimum

3. Aggregate size (maximum) - 1/2 inch

4. Air entrainment: 4-6 percent at truck discharge.

5. Chemical Admixture: Water Reducing, Pozzolon

6. Pozzolanic mineral admixture: Allowed

7. Slump: 2 inches minimum wet-mix

8. Steel Fibers: Use 25 pounds per cubic yard for 1/2 of job and 50 pounds for 1/2 of job.

B. Ensure thorough mixing of materials. If wet mix is used follow requirements of ASTM C-94 for delivery and mixing.

2.03 Equipment- Wet-Mix

1. Mixing Equipment: Capable of thoroughly mixing aggregate, cement, and water in sufficient quantity to maintain continuous placement.

2. Air Supply: Clean air adequate for maintaining sufficient nozzle velocity for all parts of the work.

Appendix E

Seepage Results

LOSSES & WASTES

(2) Conveyance losses and wastes vary throughout the season depending upon the acreage supplied and the current crop requirement, irrigation practices, and type of canal. Wastes and losses are heaviest during the spring months when needs and operating efficiencies are low and priming losses are high. Usually maximum demands come at the height of the irrigation season when crop requirements are high, the canal is in its best condition and there is little waste through inefficient operation. Canal capacity should therefore be based on such periods of maximum demand with the best possible estimate of losses and waste under such conditions. If possible, losses should be estimated from nearby operating canals of similar hydraulic properties and lengths, and type of earth or other material used for construction, including linings. If such information is not available it may be necessary to make estimates from less comparable systems and known experimental values or operating ranges based on experience further removed from the project. For purposes of project planning water supply studies, lateral losses are commonly stated as a percentage of deliveries from the main canal, and main canal losses as a percentage of the diversion into the main canal. Lateral losses range from less than 5 percent for lined systems in good condition to over 30 percent for untreated earth systems. Main canal losses may range from less than 5 percent to over 60 percent, depending upon the length of the canal and its character. In estimating water requirements, canal and lateral losses are usually combined with an allowance for operating waste in a single item. Evaporation is small in comparison to seepage and waste and is ordinarily ignored in design.

Canal seepage follows in general the laws of percolation. The loss per unit area of wetted surface varies directly with the head and permeability of the soil, inversely as the length of path. Percolation is fairly rapid when water is first turned into the canal, until the soil is fully saturated for some distance from the canal and it has expanded to fill cracks produced in drying. As the distance of movement increases, the groundwater gradient becomes the controlling measure of head rather than the depth of water in the canal. Both head and distance of travel approach a uniform condition and the permeability factor becomes a control in the measurement of seepage. For practical purposes seepage is represented by depth of water lost per day over the wetted area. Values given in Volume IX, Paragraph 4.1.2C, are repeated here for convenience:

Kind of material	Loss per day in feet
Cemented gravel and hardpan with sandy loam	0.34
Clay and clay loam	0.41
Sandy loam	0.66
Volcanic ash	0.68
Volcanic ash with some sand	0.98
Sand and volcanic ash or clay	1.20
Sandy soil with some rock	1.68
Sandy and gravelly soil	2.20
Concrete lining	0.33

The loss for the entire canal, or for the design reaches, may be estimated from seepage data in terms of depth for the material involved and stated in convenient terms; acre-feet per acre irrigated per month, cubic-feet per second, or percent of total diversion. The Moritz formula for estimating canal loss in second-feet per mile (see Volume IX, Paragraph 4.1.2C) is

$$S = 0.2\,C\,\sqrt{Q/V}$$

consideration. For unlined canals the following classification may serve as a rough guide:

Poor, where losses exceed 1.5 feet in depth per day.

Fair, where losses are from 1 to 1.5 feet per day.

Good, where losses are from .5 to 1 foot per day.

Excellent, where losses are less than .5 foot per day.

The wisdom and character of improvement will depend in each case not only upon the losses, but also upon the value of the water to be saved and the damage being done by the seepage, and whether other economies are to be secured thereby.

13. **Seepage Formula.**—The following formula is proposed as representing the results of existing data, to be used in estimating seepage to be expected from contemplated canals:

$$S = C\sqrt[3]{d}\,\frac{PL}{4{,}000{,}000 + 2{,}000\sqrt{V}}, \text{ where}$$

S = Seepage in cubic feet per second;

C = Coefficient depending on material of canal;

d = Mean depth of water in feet;

P = Wetted perimeter in feet;

L = Length of canal in feet;

V = Mean velocity of water in canal.

Values of C are as follows:

$C = 1$ = Concrete, 3 to 4 inches thick;

$C = 4$ = Clay puddle, 6 inches thick;

$C = 5$ = Thick coat of crude oil, new;

$C = 6$ = Cement plaster, 1 inch thick;

$C = 8$ = Clay puddle, 3 inches thick;

$C = 10$ = Thin oil lining; cement grout;

$C = 12$ = Clay soil, unlined;

$C = 15$ = Clay loam soil, unlined;

$C = 20$ = Medium loam, unlined.

$C = 25$ = Sandy loam, unlined;

$C = 30$ = Coarse sandy loam, unlined;

$C = 40$ = Fine sand, unlined;

$C = 50$ = Medium sand, unlined;

$C = 70$ = Coarse sand and gravel, unlined.

From: Davis, A.P. and H.M. Wilson, *Irrigation Engineering*, John Wiley & Sons, Inc., 1919.

SEEPAGE RATES*

Material	Loss (ft/day)
3" - 4" Concrete	0.03
1" Cement plaster	0.18
Cement grout	0.31
Clay soil	0.37
Clay loam	0.46
Medium loam	0.62
Sandy loam	0.77
Coarse sandy loam	0.92
Fine sand	1.23
Medium sand	1.54
Coarse sandy gravel	2.15

* Davis, A.P. and H.M. Wilson, *Irrigation Engineering*, John Wiley & Sons, Inc., p. 235, 1919 (based on a 3-ft water depth).

TABLE 4.—*Permeability of some typical canal linings*—Continued

Feature and project	As designed					As tested				Remarks
	Station		Capacity, second-feet	Water depth, feet	Wetted perimeter, feet	Length of reach, feet	Date	Water depth, feet	Seepage rate, (cfd)[1]	
	From	To								
ASPHALTIC MEMBRANES (Continued)										
Buried, Prefabricated with Glass Fiber Reinforcement (Continued)										
Boise project, Idaho (continued)										
Willow Creek Pump Canal	0+00	1+38	—	—	10.8	138	1950	—	(0.54[2])	Before lining (control)
							1950	—	0.04[2]	1/16-inch membrane with earth cover
							1951	1.13[3]	0.02	
							1955	0.77[3]	0.33	
W.C. Austin project, Oklahoma										
Altus Lateral 6.8	2+50	8+33	10	1.04	6.0	583	1950	1.04	(0.71[2])	Before lining (control)
	8+33	12+16	10	1.04	10.0	383	1950	1.04	(1.54[2])	Before lining (control)
	5+84	9+08	10	1.04	6.0	324	1950	1.04	0.10[2]	1/16-inch membrane with earth cover
	9+08	12+16	10	1.04	6.0	308	1950	1.04	0.08[2]	
Exposed, Prefabricated										
Boise project, Idaho										
Lateral 10.2-4.2	0+00	6+45	—	—	—	645	1952	—	(2.73)	Before lining (control)
	4+47	5+52	—	—	—	95	6-1953	0.84[3]	0.05	1/2-inch-thick sheets
							9-1953	0.71[3]	0.18	
							1954	0.91[3]	0.01	
							1956	0.87[3]	0.01	
							1958	0.76[3]	0.01	
	5+52	6+45	—	—	—	93	6-1953	0.73[3]	0.48	1/4-inch-thick sheets
							9-1953	0.77[3]	0.05	
							1954	0.90[3]	0.05	
							1956	0.56[3]	0.11	
Savage Test Lateral	1+49	3+39	—	1.5	9.0	190	1951	0.77[3]	(2.30)	Before lining (control)
	0+62	1+12	—	1.5	9.0	50	1953	0.78[3]	0.31	1/4-inch-thick sheets
							1954	0.81[3]	0.25	
							1955	0.67[3]	0.25	
							1958	0.80[3]	0.13	
	3+52	4+99	—	1.5	9.0	147	1951	0.69[3]	(3.05)	Before lining (control)
	6+51	7+00	—	1.5	9.0	49	1953	0.83[3]	0.08	1/2-inch-thick sheets
							1954	0.81[3]	0.18	
							1955	0.58[3]	0.53	
							1958	0.79[3]	0.01	
PORTLAND CEMENT CONCRETE AND MORTAR										
Unreinforced Concrete										
Central Valley project California										
Friant-Kern Canal	3644+07	3673+56	4000 to 5000	17.2	119	2,949	1950	17.2	0.07[2]	3 1/2 inches thick
Rio Grande project, New Mexico-Texas										
West Canal	50+84	273+32	—	—	—	22,248	1949	—	0.83	4 inches thick. Seepage measured by inflow-outflow methods
	273+32	314+76	—	—	—	4,144	1949	—	0.50	
	314+76	342+87	—	—	—	2,811	1949	—	0.26	
Concrete Blocks										
Boise project, Idaho										
"D" Line Canal	Vicinity mile 13.5		—	—	28.4	400	1951	2.87[3]	(0.43)	Unlined adjacent reach (control)
					25.1	400	1951	2.55[3]	0.20	Lined reach
Shotcrete (Mortar)										
Gila project, Arizona										
Lateral A-8.9-N	—	—	14	—	8.5	1,226	1950	14.0	0.03	1 1/2 inches thick
Lateral B-3.7-1.8	—	—	14	—	8.5	614	1950	14.0	0.03	1 1/2 inches thick

LCCL-T4 (2 OF 3)

Appendix F

Laboratory Test Results

Shotcrete compressive strength tests (lbf/in^2).

Description	Date	Core Samples			
		A	B	C	Avg
North Unit Canal Steel fiber reinforced 50 lb/yd^3	2-27-91	4156	4401	3708	4650
	2-27-91	5460	4319	5827	
	2-28-91	4034	5134	4808	
25 lb/yd^3	2-28-91	6112	5053	5827	5180
	2-28-91	5134	5012	5175	
	2-29-91	4971	5338	4808	
	3-02-91	4442	5053	5175	
Phillips polyfibers 3 lb/yd^3	3-02-91	3464	3219	3545	4270
	3-03-91	4605	4523	3790	
	3-04-91	4971	4482	5786	
1-1/2 lb/yd^3	3-04-91	5134	4645	5420	4730
	3-05-91	4034	4319	4849	
Fibermesh polyfibers 3 lb/yd^3	3-05-91	4727	3423	4727	3890
	3-05-91	3993	3504	2934	
	3-10-91	4645	3749	4401	
	3-10-91	3545	3382	3627	
1-1/2 lb/yd^3	3-11-91	4900	4523	4605	4680
Unreinforced	2-26-91	5094	5379	4686	4630
	3-33-91	4808	4645	5012	
	3-12-91	4360	3708	4645	
	3-12-91	4360	4360	4482	
ARNOLD CANAL Phillips polyfibers 1-1/2 lb/yd^3	3-20-91	3586	4238	4645	4160
	3-20-91	4808	5216	4279	
	3-23-91	2486	3464	3953	
	3-23-91	4360	4482	4401	
Unreinforced	3-23-91	3790	4319	4645	4250

CENTURY WEST ENGINEERING CORPORATION

MAIL: POST OFFICE BOX 1174 BEND, OREGON 97709 (503) 388-3500

RECEIVED DEC 13 1991

GROUT TEST REPORT

PACIFIC EROSION CONTROL	Client's No.
Project: ARNOLD IRRIGATION CANAL LINING	File No.
Contractor:	Report No.

MIX DESIGN (NUMBER ________)

QUANTITIES PER CUBIC YARD OF GROUT

Cement

Fine Aggregate

Coarse Aggregate

Water

Admixtures:

Required Strength:

TICKET AND FIELD DATA

Field Technician: DWK	Pour Location in Structure:		
Specimen Size:	Slump (If Requested):	Total Quantity: Cu. Yds.	Number of Specimens: 2
Temperature: 50 °F	Grout Temperature: 63 °F	Weather:	
Grout Supplier: BEND READY MIX	Ticket No.:	Batch Time:	Time Sampled: 10:10 AM / Date Moulded: 11/11/91

Reinforcing Steel Inspection (if requested): _____ According to Specifications
_____ Not According to Specifications - See Notes Below

LABORATORY REPORT

Date recieved	Delivered by	Field Cure - Days	Lab Technicians:
11/13	DWK	2	DWK / /

CYLINDER NO.	DATE TESTED	AGE AT TEST	LOAD POUNDS	STRENGTH P.S.I.	DATE REPORTED	REMARKS
4714	12-9	28 DAYS	99,000	3501 P.S.I.	12-11-91	NON FIBER
4715	12-9	28 DAYS	71,000	2511 P.S.I.	12-11-91	FIBER
		DAYS		P.S.I.		
		DAYS		P.S.I.		
		DAYS		P.S.I.		
		DAYS		P.S.I.		

Notes:

CENTURY WEST ENGINEERING CORPORATION
MAIL: POST OFFICE BOX 1174
BEND, OREGON 97709
(503) 388-3500

RECEIVED DEC 13 1991

GROUT TEST REPORT

: PACIFIC EROSION	Client's No.
Project: ARNOLD IRRIGATION CANAL	File No.
Contractor:	Report No.

MIX DESIGN (NUMBER ________)

QUANTITIES PER CUBIC YARD OF GROUT

Cement

Fine Aggregate

Coarse Aggregate

Water

Admixtures:

Required Strength:

TICKET AND FIELD DATA

Field Technician: CLIENT	Pour Location in Structure		
Specimen Size L x D 4.04 x 3.96	Slump (If Requested)	Total Quantity Cu. Yds.	Number of Specimens 4
Temperature °F	Grout Temperature °F	Weather	
Grout Supplier	Ticket No.	Batch Time / Time Sampled	Date Moulded 11/11/91

Reinforcing Steel Inspection (if requested): ______ According to Specifications
______ Not According to Specifications - See Notes Below

LABORATORY REPORT

Date recieved	Delivered by	Field Cure - Days	Lab Technicians:
11/13/91	DWK	2	DWK / / /

CYLINDER NO.	DATE TESTED	AGE AT TEST	LOAD POUNDS	STRENGTH P.S.I.	DATE REPORTED	REMARKS
4735	11-18	7 DAYS	30,500	1653 P.S.I.	12-10-91	W/OUT FIBER
4736	12-9	28 DAYS	29,500	1881 P.S.I.	12-10-91	" "
4737	11-18	7 DAYS	31,500	1670 P.S.I.	12-10-91	W/FIBER
4738	12-9	28 DAYS	32,500	2027 P.S.I.	12-10-91	"
		DAYS		P.S.I.		
		DAYS		P.S.I.		

Notes:

#	AREA
35	15.68
36	~~16.03~~
37	16.03
38	

CENTURY WEST ENGINEERING CORPORATION
MAIL: POST OFFICE BOX 1174 (503) 388-3500
BEND, OREGON 97709

RECEIVED DEC 13 1991

GROUT TEST REPORT

Client: PACIFIC EDISON	Client's No.
Project: ARNOLD IRRIGATION CANAL	File No.
Contractor:	Report No.

MIX DESIGN (NUMBER ________)

QUANTITIES PER CUBIC YARD OF GROUT

Cement

Fine Aggregate

Course Aggregate

Water

Admixtures:

Required Strength:

TICKET AND FIELD DATA

Field Technician: CLIENT	Pour Location in Structure			
Specimen Size	Slump (If Requested)	Total Quantity Cu. Yds.	Number of Specimens 2	
Temperature °F	Grout Temperature °F	Weather		
Grout Supplier	Ticket No.	Batch Time	Time Sampled	Date Moulded 11/12/91

Reinforcing Steel Inspection (If requested): ______ According to Specifications
______ Not According to Specifications - See Notes Below

LABORATORY REPORT

Date recieved	Delivered by	Field Cure - Days	Lab Technicians:
11/13/91	RAW	1	DW/ / /

CYLINDER NO.	DATE TESTED	AGE AT TEST	LOAD POUNDS	STRENGTH P.S.I.	DATE REPORTED	REMARKS
4739	11-19	7 DAYS	28500	1529 P.S.I.	11-19-91	
4740	12-10	28 DAYS	35,500	1840 P.S.I.	12-11-91	
		DAYS		P.S.I.		
		DAYS		P.S.I.		
		DAYS		P.S.I.		
		DAYS		P.S.I.		

Notes: # AREA
39 28500 ÷ 15.34 x 95% = 1529
40 35,500 ÷ 16.40 x 95% = 1840

CENTURY WEST ENGINEERING CORPORATION

MAIL: POST OFFICE BOX 1174 (503) 388-3500
BEND, OREGON 97709

GROUT TEST REPORT

PACIFIC EROSION	Client's No.
Project: ARNOLD IRRIGATION CANAL	File No.
Contractor:	Report No.

MIX DESIGN (NUMBER ________)

QUANTITIES PER CUBIC YARD OF GROUT

Cement

Fine Aggregate

Coarse Aggregate

Water

Admixtures:

☆ Required Strength:

TICKET AND FIELD DATA

Field Technician: CLIENT	Pour Location in Structure		
Specimen Size	Slump (If Requested)	Total Quantity Cu. Yds.	Number of Specimens: 2
Temperature °F	Grout Temperature °F	Weather	
Grout Supplier	Ticket No.	Batch Time	Time Sampled
Date Moulded: 11-15-91			

Reinforcing Steel Inspection (if requested): ______ According to Specifications
______ Not According to Specifications - See Notes Below

LABORATORY REPORT

Date recieved	Delivered by	Field Cure - Days	Lab Technicians:
11/14/91	RAW	1	DWK / DWK

CYLINDER NO.	DATE TESTED	AGE AT TEST	LOAD POUNDS	STRENGTH P.S.I.	DATE REPORTED	REMARKS
4741	11-20	7 DAYS	25000	1318 P.S.I.	11-22-91	
4742	12-11	28 DAYS	43,000	2284 P.S.I.	12-16-91	
		DAYS		P.S.I.		
		DAYS		P.S.I.		
		DAYS		P.S.I.		
		DAYS		P.S.I.		

Notes:

#	AREA	
41	16.12	25000 X .85 ÷ 16.12 = 1318
42	16.00	43,000 X .85 ÷ 16.00 = 2284

PREVIOUS 7 DAY BREAK RESULTS ARE INCORRECT, USE THESE BREAK RESULTS

CENTURY WEST ENGINEERING CORPORATION

MAIL: POST OFFICE BOX 1174
BEND, OREGON 97709
(503) 388-3500

CLIENT: Pacific Errosion
DATE RECEIVED: 13 NOV 91

LAB NO.: 4803
SAMPLE NO.: II

COMPRESSIVE STRENGTH OF DRILLED CORES

CORE #: 2 DATE OF POUR: 11/11/91 DATE OF TEST: 12/24/91 AGE OF CORES: 43 days
SAMPLE REPRESENTS: Canal Grout Liner
LENGTH= 4" DIAMETER= 1 6/8" AREA= 2.405 L/D= ______ CORRECT. FACT. —
TOTAL LOAD= 7200 lbs X COR. FAC. OF — = 7200 ÷ AREA OF 2.405 = 2993 PSI
COMMENTS: Cores taken from [illegible] samples. (SS)

CORE #: ______ DATE OF POUR: ______ DATE OF TEST: ______ AGE OF CORES: ______
SAMPLE REPRESENTS: ______
LENGTH= ______ DIAMETER= ______ AREA= ______ L/D= ______ CORRECT. FACT. ______
TOTAL LOAD ______ X COR. FAC. OF ______ = ______ ÷ AREA OF ______ = ______ PSI
COMMENTS: ______

CORE #: ______ DATE OF POUR: ______ DATE OF TEST ______ AGE OF CORES: ______
SAMPLE REPRESENTS: ______
LENGTH= ______ DIAMETER= ______ AREA= ______ L/D= ______ CORRECT. FACT. ______
TOTAL LOAD ______ X COR. FAC. OF ______ = ______ ÷ AREA OF ______ = ______ PSI
COMMENTS: ______

CORE #: ______ DATE OF POUR: ______ DATE OF TEST: ______ AGE OF CORES: ______
SAMPLE REPRESENTS: ______
LENGTH= ______ DIAMETER= ______ AREA= ______ L/D= ______ CORRECT. FACT. ______
TOTAL LOAD ______ X CORR. FAC. OF ______ = ______ ÷ AREA OF ______ = ______ PSI
COMMENTS: ______

NOTES: ______

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.