MOST ASKED QUESTIONS ABOUT GEOSYNTHETIC CANAL LININGS DO THEY WORK? AND HOW MUCH DO THEY COST?

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ABSTRACT

The Bureau of Reclamation (Reclamation) is collaborating with several irrigation districts in central Oregon to demonstrate and evaluate various canal linings under actual field conditions. This paper shows the results of more than 7 years of field testing and includes a series of photographs showing the subgrades, construction, and required maintenance. This paper also examines the effectiveness of the various geosynthetics and other materials to control seepage and compares construction costs.

Uncontrolled field testing of 29 types of geosynthetic canal liners exposed the various materials to very harsh conditions including freeze/thaw, wet/dry, direct and indirect sunlight, extreme rocky subgrades, wildlife (elk, deer, rodents, cattle, etc.) and man. Canals in this study had fractured basalt bottoms and typically lost 35 to 50 percent of the flow to seepage. Preconstruction seepage rates as determined by full-scale ponding tests ranged from 0.6 to 4.2 ft^3/ft^2-day. Following the installation of the linings, average seepage rates were reduced to less than 0.1 ft^3/ft^2-day.

BACKGROUND

This paper describes the Deschutes Canal Lining Demonstration Project. To date, 29 test sections have been constructed on seven irrigation districts. The lining materials include combinations of geosynthetics, concrete grout, shotcrete, and elastomeric coatings. The test sections are being evaluated for durability and effectiveness in reducing seepage. The test sections now range in age from 6 months to 8 years, and the differences in performance are becoming apparent, see table 1.

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Table 1. - 6½ Year Condition Assessment and Construction Costs

	Test Section Description	Cost $/ft²	Condition (age)	Comments
A-1	Polyethylene Geocomposite with 3-in Shotcrete cover	$2.06	Excellent (7 years)	No problems
A-2	30 mil VLDPE with 3-in Shotcrete cover	$2.14	Excellent (6½ years)	No problems
A-3	Exposed 80 mil HDPE	$1.38	Very good (6½ years)	Several small tears and cuts
A-4	Exposed PVC Geocomposite	$1.05	Very good (7 years)	Several small tears and cuts Unbonded geotextile seams
A-5	Exposed 45 mil CSPE	$1.11	Very good (7 years)	Several small tears and cuts
A-6	Exposed 36 mil CSPE Geocomposite	$1.03	Very good (7 years)	Several small tears and cuts
A-7	40 mil PVC with 3-in Grout-filled mattress	$2.36	Excellent (7½ years)	No problems
A-8	3-in Grout-filled Mattress	$1.86	Excellent (7 years)	No problems
A-9	Exposed 60 mil VLDPE with Grout-filled Mattress on Side Slopes only	$1.79	Removed from Study after 28 months	Liner "whales" were impeding flow
A-10	Exposed 60 mil HDPE with Grout-filled Mattress on Side Slopes only	$1.79	Removed from Study after 28 months	Liner "whales" were impeding flow
N-1	SPUF with Urethane Protective Coating	$4.33	Poor (6 years)	Partial Foam wash-out, Invert replaced with RCC
N-2	SPUF with modified Urethane Protective Coating	$3.92	Poor (6½ years)	Partial Foam wash-out, Invert replaced with RCC
N-3	Woven Geotextile with modified Urethane Coating	$2.64	Failed (1st day)	Complete Failure (May 1993)
N-4	Needle-punched Geotextile with modified Urethane Coating	$2.64	Failed (1st day)	Complete Failure (May 1993)
N-6	3-in Shotcrete with steel fibers	$1.59	Excellent (7 years)	No problems
N-7	3-in Shotcrete with Polyfibers	$1.47	Excellent (7 years)	No problems
N-8	3-in Shotcrete with fibrillated Polyfibers	$1.47	Excellent (7 years)	No problems

	Test Section Description	Cost $/ft²	Condition (age)	Comments
N-9	3-in Unreinforced Shotcrete	$1.33	Excellent (7 years)	No problems
T-1	Neoprene-Asphalt Emulsion over an Existing Concrete Flume	$1.70	Poor (5 years)	Tore away from Invert. Removed from study
T-2	Neoprene-Asphalt Emulsion over a Sandblasted Steel Flume	$2.16	Very Good (5 years)	40-50 blisters in the Invert
T-3	Neoprene-Asphalt Emulsion over a Broomed Steel Flume	$1.40	Very Good (4 years)	About 40 blisters in the Invert
L-1	Exposed 160 mil Bituminous Geomembrane	$1.39	Very Good (5 years)	Partial wash-out has been repaired
J-1	Exposed 160 mil Bituminous Geomembrane	$1.39	Excellent (1½ year)	
O-1a	Covered Geosynthetic Clay Liner	$0.82	Excellent (1 year)	
O-1b	Covered Geosynthetic Clay Liner	$0.87	Excellent (1 year)	
O-2a	Exposed Geosynthetic Clay Liner	$0.76	Very Good (1 year)	Some curling of exposed edges
O-2b	Exposed Geosynthetic Clay Liner	$0.81	Very Good (1 year)	Some curling of exposed edges
O-3a	Exposed 45-mil EPDM with 8-oz geotextile on sideslopes only	$0.84		New
O-3b	Exposed 45-mil EPDM with 8-oz geotextile on sideslopes only and covered invert	$0.87		New
O-4	Exposed 30-mil LLDPE with 8-oz geotextile on sideslopes only	$0.78		New
F-1	Exposed 45-mil Reinforced Polypropylene	$0.90	Excellent (1 year)	
N-5	Roller-Compacted Concrete Invert only	$2.00	Excellent (2 year)	

Geology

Oregon's volcanic geology contributes to high seepage rates (Gilbert, 1991), and canals in the area typically lose 35 to 50 percent of their water to seepage because they have fractured basalt bottoms (Fig. 1) and/or sides of highly porous soil, or soil and rock (Fig. 2). The fractured basalt subgrade also hinders excavation in the canal prism. Therefore, specialized lining technologies are needed to reduce seepage in these areas. Subgrade conditions for the one test section in Oklahoma were mostly fine sands with some gravel.

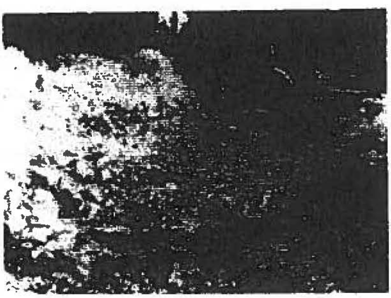

Fig. 1. Basalt Subgrade

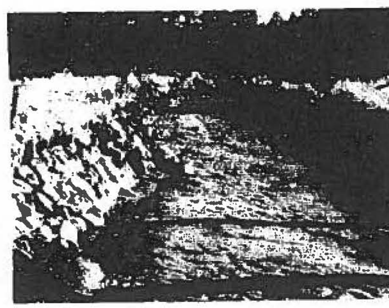

Fig. 2. Invert Sediment

Ponding Test Results

Both pre- and post-construction ponding tests were conducted to determine seepage rates on the Arnold and on the North Unit test sections. Pre-construction seepage rates as determined by full-scale ponding tests ranged from 0.6 to 4.2 ft^3/ft^2-day (Swihart, 1994). Following the installation of the linings, average seepage rates were reduced to less than 0.1 ft^3/ft^2-day (Burnett, 1997). Additional tests are planned for inclusion in the final report.

Test Section A-1 - Polyethylene Geocomposite with 3-inch Shotcrete Cover

Const. Cost = \$2.06/ft^2; L = 1,000 ft; A = 30,000 ft^2

Condition: Excellent - After almost 6 years service, the shotcrete lining is in excellent condition, completely protecting the underlying Petromat geosynthetic liner from weathering and mechanical damage (Fig. 3). The only significant damage is that the shotcrete cover is showing extensive cracking over the anchor trench where the shotcrete was tapered-down to a thickness of less than 1 in (Fig. 4). Tapering of the shotcrete over the anchor trench is not recommended for future installations; instead the shotcrete should maintain a minimum thickness of 2 inches over the anchor trench.

Maintenance: Minimal maintenance required to date.

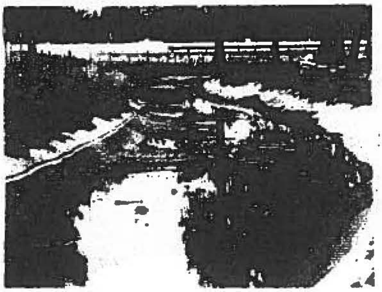

Fig. 3 - Overview of both A-1 and A-2

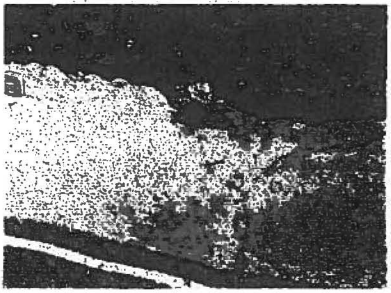

Fig. 4 - Cracking over anchor trench at top

Test Section A-2 - 30-mil textured VLDPE with geotextile cushion & 3-inch Shotcrete Cover

Const. Cost = \$2.14/ft^2; L = 500 ft; A = 15,000 ft^2

Condition: Excellent - After 5½ years, the shotcrete lining is in excellent condition, completely protecting the underlying VLDPE geosynthetic liner (Fig. 3). Dozens of transverse contraction cracks have developed on each bank. Some new cracks appear every year, and many of the old cracks grow in length, but do not widen significantly. Cracking in the thin, tapered shotcrete over the anchor trench is moderate to severe (Fig. 4). Again, tapering of the shotcrete over the anchor trench is not recommended for future installations, instead the shotcrete should maintain a minimum thickness of 2 inches over the anchor trench.

<u>Maintenance</u>: Minimal maintenance requirements to date.

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

<u>Const. Cost</u>: \$1.38/ft^2; L: 500 ft; Area: 15,000 ft^2

<u>Condition</u>: Very Good - After 5½ years of service (Fig. 5), the exposed HDPE liner is performing well, with only a few small tears over sharp subgrade rocks (Fig. 6).

<u>Maintenance</u>: Minimal maintenance required to date.

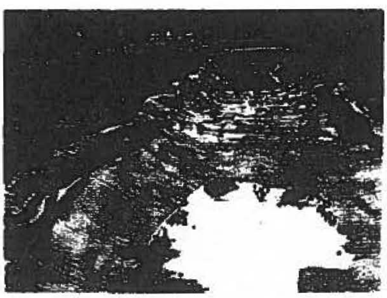

Fig. 5 - Overview of A-3

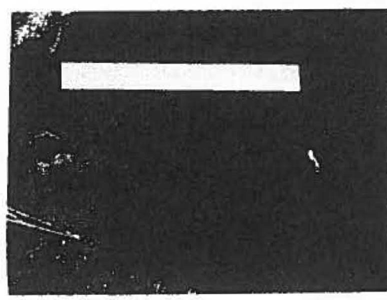

Fig. 6 - Tear in side wall above water surface

Test Section A-4 - Inverted PVC Geocomposite with geotextile cushion

<u>Const. Cost</u> = \$1.05/ft^2; L = 1,000 ft; A = 30,000 ft^2

<u>Condition</u>: Very Good - After 6 years (Fig. 7), the PVC is holding up well with no visible deterioration or stiffening, even where exposed. The geotextile cover is slowly weathering away (especially where unbonded at seams). Sediment (up to 1 foot deep) has collected in the invert providing additional UV protection. Some aquatic growth is impeding flow.

<u>Maintenance</u>: Minor maintenance required to date to

repair damage (Fig. 8).

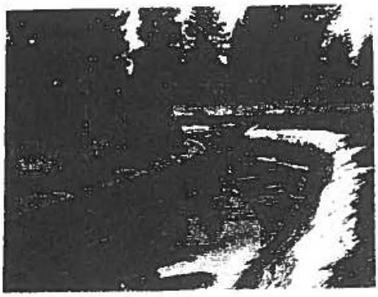

Fig. 7 - Overview of A-4

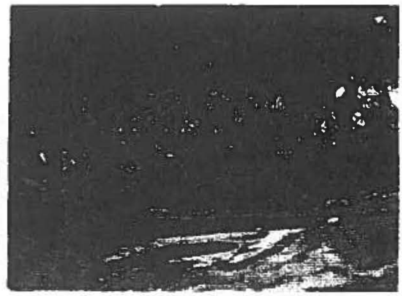

Fig. 8 - Tree fell onto liner during storm

Test Section A-5 - Exposed 45-mil CSPE with 16-ounce geotextile cushion

Const. Cost = $1.11/ft²; L = 500 ft; A = 15,000 ft²

Condition: Very Good - After 6 years, the exposed CSPE geomembrane (Fig. 9) is holding up well. Standing water and a layer of sediment covers almost the entire invert, typically 0.5 to 1.0 foot deep. Some vegetation is growing but has little effect on flow to date. A couple of small tears have developed at the anchor trench (Fig. 10) and a sharp subgrade rock has punctured the liner at the waterline.

Maintenance: Minor maintenance required.

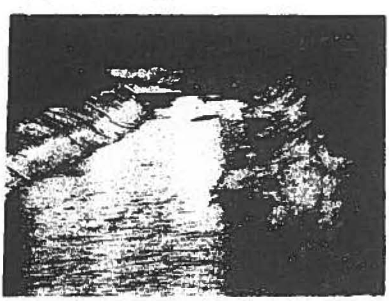

Fig. 9 - Overview of A-5 and A-6

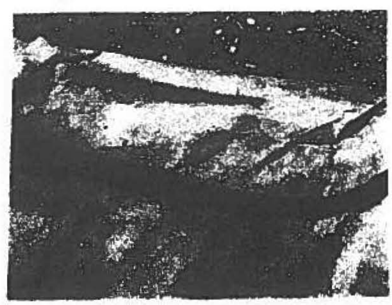

Fig. 10 -Tears at anchor trench

Test Section A-6 - Exposed 36-mil CSPE geocomposite

Const. Cost = \$1.03/ft^2; L = 500 ft; A = 15,000 ft^2

Condition: Very Good - After 6 years, the exposed CSPE geomembrane (Fig. 9) is holding up well. The upstream transition between Test Sections 5 and 6 has a transverse adhesive-bonded seam which is working well. Backhoe operators have caused more damage to the exposed linings to date than any other element. A few small tears near the anchor trench need to be repaired.

Maintenance: Minor maintenance required to date.

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

Const. Cost = \$2.36/ft^2; L = 800 ft; A = 24,000 ft^2

Condition: Excellent - After 6½ years, the grout-filled mattress is in excellent condition, completely protecting the underlying PVC geomembrane. The mattress is fairly uniformly grouted in spite of the uneven rocky subgrade (Fig. 11). The outer fabric is beginning to deteriorate (Fig. 12), especially where subjected to abrasion. When the water is turned off, this test section holds water all winter, while the adjacent Test Section A-8 holds water for only a couple of weeks. This side-by-side comparison demonstrates the difference in seepage rates due to the geomembrane underliner.

Maintenance: Minor maintenance required to date.

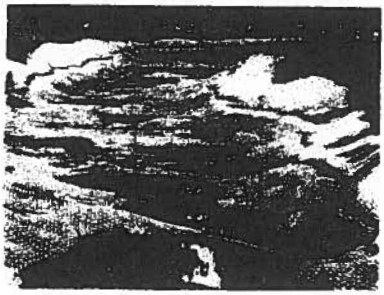

Fig. 11 - Overview of A-7 and A-8

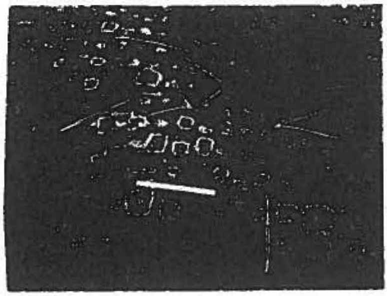

Fig. 12 - Mattress fabric is wearing away

Test Section A-8 - 3-inch grout-filled mattress

Const. Cost = $\$1.86/ft^2$; L = 700 ft; A = 21,000 ft^2

Condition: Excellent - After 6 years, the grout-filled mattress is in excellent condition with no freeze/thaw damage (Fig. 11). The first 200 feet with zippered seams has a much neater appearance than the second 500 feet with sewn seams. The grout-filled mattress is well tied-in to the bridge, with no gaps that would allow seepage. The outer fabric of the grout mattress is in good condition, with little deterioration, except for one location on the left bank where the geotextile has worn away, and several concrete "bricks" are missing.

Maintenance: Minor maintenance required to date.

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

Const. Cost = $\$1.79/ft^2$; L = 1,000 ft; A = 30,000 ft^2

Condition: Removed from study after 2 ½ years - Liner "whales" were restricting flow (Fig. 13). Attempts to deflate the "whales" with knife-cuts, and attempts to ballast with concrete blocks were largely unsuccessful as the "whales" tended re-appear elsewhere. Figure 14 shows contractor patching numerous holes, tears, and rips from sharp subgrade rocks. Eventually, the invert liner was removed with the grout-filled mattress left in place on the sideslopes. The cause of the "whales" in Test Sections A-9 and A-10 was never resolved. Volcanic gases are suspected to be the cause.

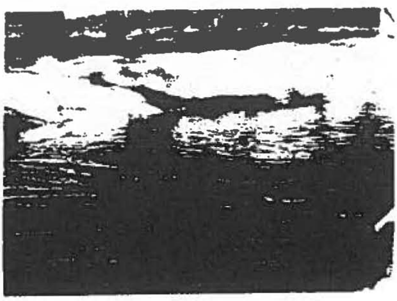

Fig. 13 - Liner "whale" impeding flow

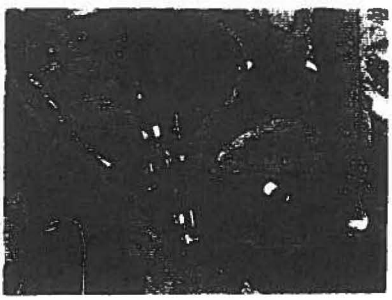

Fig. 14- Patching of tears in geomembrane

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

Const. Cost = $1.79/ft^2; L = 1,000 ft; A = 30,000 ft^2

Condition: Removed from study after 2 ½ years - This test section experienced the same problems with liner "whales" as Test Section A-9. The exposed HDPE was removed in March 1995, and this test section was abandoned. The grout-filled mattress on the side-slopes will be left in place. In many locations, the imported sand bedding had completely washed away, indicating there may have been significant flow beneath the liner.

Test Section N-1 - SPUF with urethane protective coating
Test Section N-2 - SPUF with modified urethane protective coating

Const. Cost N-1 = $4.33/ft^2; L = 300 ft; A = 18,000 ft^2

Const. Cost N-2 = $3.92/ft^2; L = 300 ft; A = 18,000 ft^2

Condition: Partially failed - After 5 years, most of the invert foam has washed out of these test sections (Fig. 15). The washout initiated in the first few weeks of service just below the drop at the start of Test Section N-1 where loose sand and gravel deposits offered little uplift resistance to the buoyant foam (Fig. 16). The high velocities then undercut large, loose subgrade rocks, allowing more foam to break free. The failure then propagated downstream washing out the invert foam in Test Section N-2.

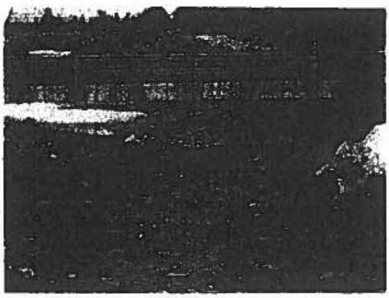

Fig. 15 - View after fifth year

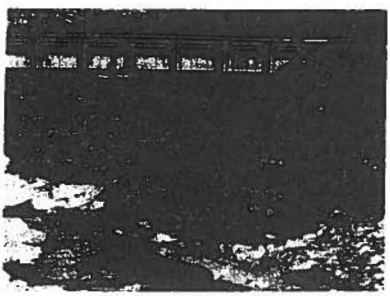

Fig. 16 - View after first year

Test Section N-3 - Woven geotextile with spray-applied modified urethane coating

Test Section N-4 - Needle-punched geotextile with spray-applied modified urethane coating.

Const. Cost (both) = $\$2.64/ft^2$; L = 300 ft; A = 18,000 ft^2

Condition: Complete failure - On the first day of service, large sections of the geotextile liners washed out resulting in complete failure (Fig. 17 and 18).

Fig. 17 - View of foam anchoring system

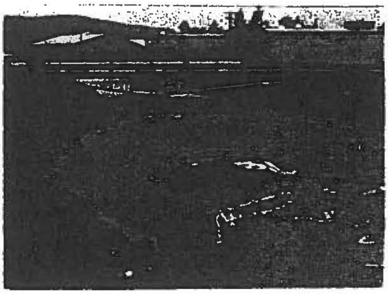

Fig. 18 - Lining floating downstream

Test Section N-6 through N-9 - General comments apply to all 3-inch shotcrete sections:

Condition: Excellent - After 6 years all the shotcrete is in excellent condition. No visible differences exist in the performance of the four shotcrete test sections. No freeze/thaw damage is evident. Small pools (Fig. 19) are present on all four test sections, even several weeks after water turn off, indicating low seepage rates. Contraction cracks on the side walls (Fig. 20) have developed every 100 to 200 feet. Crack width varies from hairline to 1/8-inch. The thickness of the shotcrete is highly variable (ranging from 1 to 6 inches thick) because of the uneven subgrade conditions, and normal problems with field installation quality control. Many large rocks (up to 1 foot in diameter) are collecting in the canal invert (perhaps rolled in by local youths). Vegetation is growing out of cracks in the shotcrete near the top of side slopes.

Table 2 - N-6 through N-9 Summary of Basic Data

Section	Description	Cost ($/ ft^2)	Length (ft)	Area (ft^2)
N-6	shotcrete reinforced with steel fibers	$1.59	500	30,000
N-7	shotcrete reinforced with polypropylene fibers	$1.47	500	30,000
N-8	shotcrete reinforced with fibrillated polypropylene fibers	$1.47	500	30,000
N-9	unreinforced shotcrete	$1.33	500	30,000

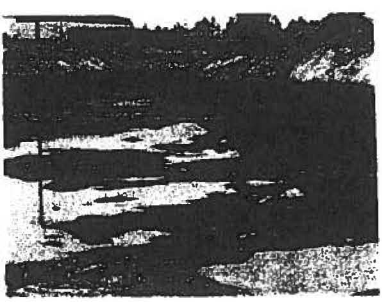

Fig. 19 - Small pools holding water in winter

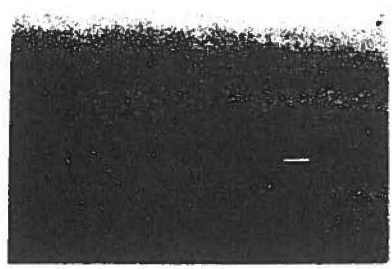

Fig. 20 - Contraction cracks in side walls

Test Section T-1 - Neoprene asphalt over an existing concrete flume

Const. Cost = $1.70/ft^2; L = 175 ft; A = 1,575 ft^2

Condition: Poor - After 4 years, the membrane is completely disbonded (due to high velocities) in the invert and has rolled up into the corners against the side walls (Fig. 21). Material on the vertical side walls has lots of small tears and pinholes (Fig. 22).

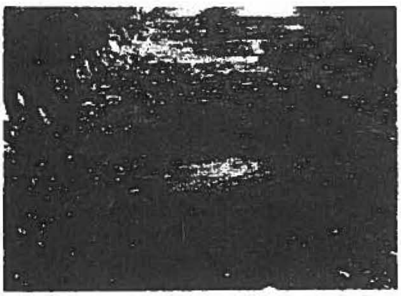

Fig. 21 - Material rolled up into corners

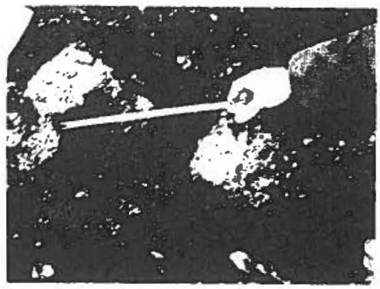

Fig. 22 - Small holes on side walls

Test Section T-2 - Neoprene asphalt over a sandblasted steel flume

Test Section T-3 - Neoprene asphalt over a broomed steel flume

Const. Cost T-2 = $2.16/ft^2; L = 465 ft; A = 7,870 ft^2

Const. Cost T-3 = $1.40/m^2; L = 265 ft; A = 4,540 ft^2

Condition: Very Good - After 3 to 4 years the membrane is well bonded to 99 percent of the steel flume (Fig. 23). No leakage is evident. Numerous blisters (Fig. 24) have developed where the membrane is poorly bonded to underlying old tar material.

Maintenance: Minor maintenance required to repair blisters.

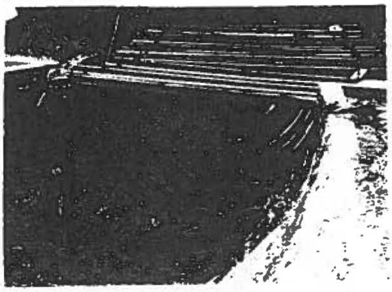

Fig. 23 - View of coated steel flume

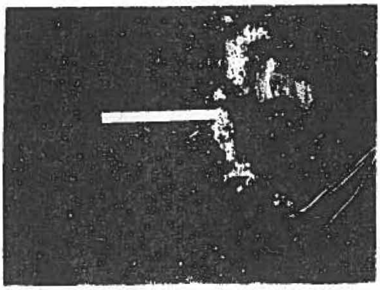

Fig. 24 - Blisters formed on old tar

Test Section L-1 - Exposed 160-mil bituminous geomembrane

Const. Cost = $1.39/ft^2$; L = 2,400 ft; A = 70,000 ft^2

Condition: Very Good - After 4 years of service (Fig. 25), the geomembrane is in very good condition. Figure 26 shows a piece of new material on top of the 4-year-old material. The alligator cracking began to appear after about one year, but the material remains quite flexible.

Maintenance: Flood waters damaged the anchor berm, requiring minor repairs.

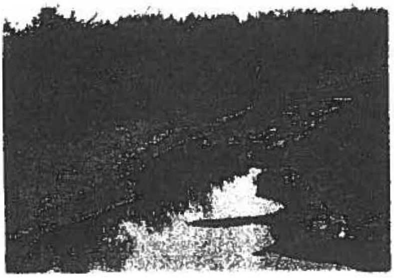

Fig. 25 - View of canal after 4 years

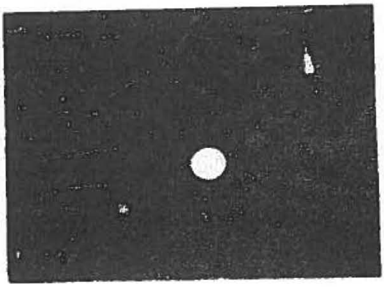

Fig. 26 - Comparison of liner (new versus old)

Test Section J-1. - Exposed 160-mil bituminous geomembrane

Const. Cost = $\$1.39/ft^2$; L = 900 ft; A = 7,215 ft^2

Condition: This new installation (only 6 months old) over fractured basalt (Fig. 27) has not yet gone through a full irrigation season (Fig. 28).

Maintenance: None to date.

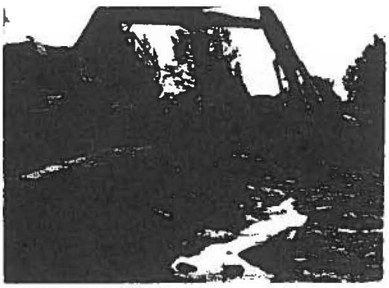

Fig. 27 - Trackhoe trying to excavate basalt

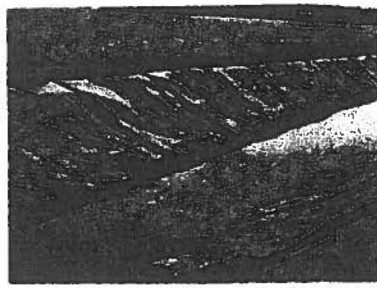

Fig. 28 - View of completed canal

CONCLUSIONS

How Much Do They Cost?

- This study has identified several effective lining technologies with construction costs between \$1.05 to $\$2.36/ft^2$.

Exposed geomembrane	$\$1.05 - \$1.79/ft^2$
Concrete alone	$\$1.33 - \$1.86/ft^2$
Geomembrane with concrete cover	$\$1.79 - \$2.36/ft^2$

Do They Work?

- Seepage reduction - Post-construction ponding tests showed that seepage had been reduced by 90 to 99 percent depending on the lining material. As expected, the 5-year ponding tests show some increase in seepage; however, seepage rates have still been reduced by 80 to 95 percent depending on the lining material. Geomembranes with concrete cover appear to provide the greatest long-term effectiveness.

- Maintenance - Test sections with exposed geomembranes are subject to mechanical damage and will probably require more maintenance than either concrete linings or geomembranes with concrete cover.

- Durability - Concrete linings have a proven life expectancy of 30 to 50 years. Since geomembranes are relatively new material, exposed geomembranes only have a proven life expectancy of about 20 years at this time.

- Future studies - The long-term effectiveness and durability of these 23 test sections will be addressed in a series of "Durability Reports." Life-cycle costs will include initial construction costs, maintenance costs, and design life (durability). Future ponding tests will be used in Cost/Benefit analysis to calculate the cost of conserved water ($/acre-foot).

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