CHAPTER 4
SEEPAGE ANALYSIS

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

Preconstruction Ponding Tests

Arnold

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

North Unit

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

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

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

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

Ochoco

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

Postconstruction Ponding Tests

Arnold Ponding Tests

The Arnold test sections were constructed in 1992, and ponding tests were performed in 1991 (preconstruction), 1993 (1 year postconstruction), 1997 (5 years postconstruction), and 1998 (6 years postconstruction). Ponding tests were planned for 10 years after construction, but they were not performed because of scheduling conflicts. The results from all the ponding tests are summarized in table 14. The 1997 ponding tests used concrete dikes that were poorly anchored to the canal invert, and large amounts of leakage under the dikes caused large uncertainties in the test results. Therefore, the 1997 results are shown as a range in table 14, and some of the ponding tests were repeated in 1998 with earthen dikes.

North Unit Ponding Test

The original eight North Unit test sections (N-1 thru N-4, and N-6 thru N-9) were constructed in 1992. However, test sections N-1 through N-4 failed in the first couple of years and were torn out and replaced with RCC in the invert (1997). Shotcrete was used on the side slopes (1998). Therefore, ponding tests for test sections N-1 through N-5 represent the following: 1991 (preconstruction), 1996 (preconstruction), 1998 (1 year postconstruction RCC invert only), 2001 (3 years postconstruction - RCC Invert with shotcrete side slopes). The locations of the ponding tests is shown in figure 8.

Test sections N-6 through N-9 still contain the original shotcrete invert and side slopes constructed in 1992, and these ponding tests represent the following: 1991 (preconstruction), 1994 (2-year postconstruction), 1998 (6-year post-construction), and 2001 (10-years postconstruction).

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

Ochoco Ponding Tests

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

Table 14.—Arnold Canal Ponding Tests

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

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

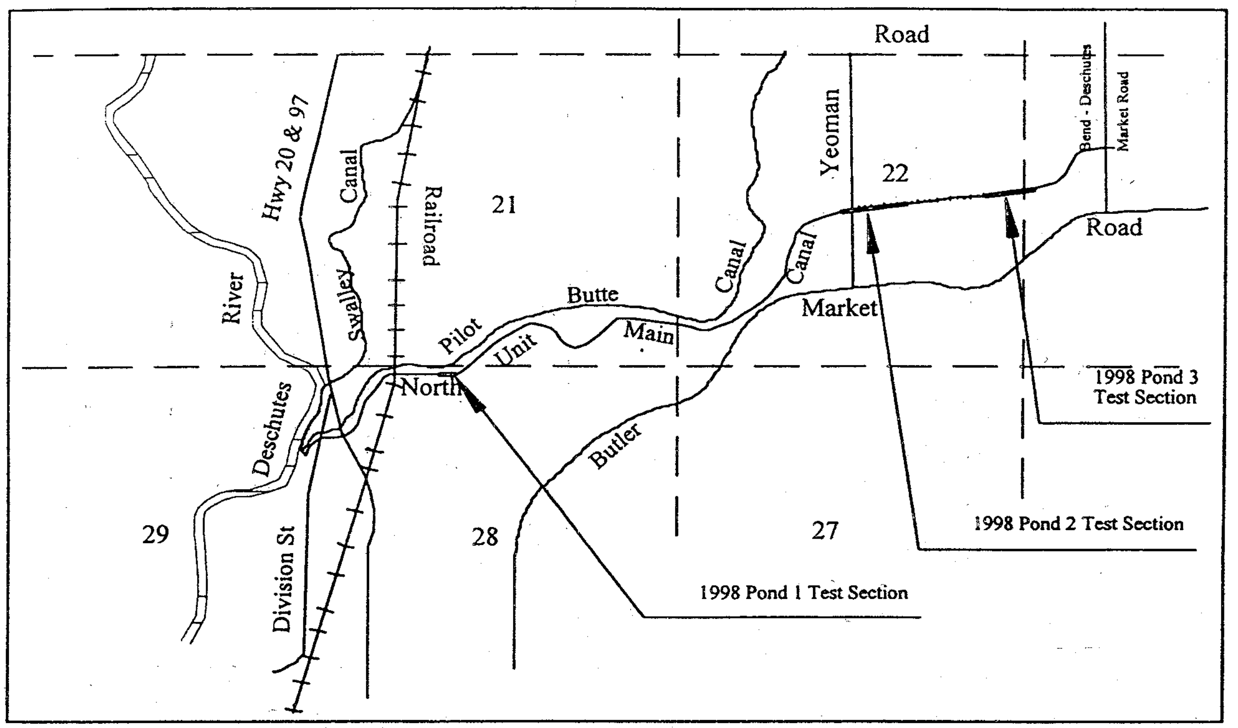

Figure 8.—General Location Map for North Unit Main Canal 1998 Ponding Tests.

Table 15.—North Unit Canal Ponding Tests

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

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

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

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

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

Table 17.—Ochoco Canal Ponding Tests

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

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

Effectiveness

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

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

Table 18.—Test section results

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

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

Exposed Geomembrane—Exposed geomembrane includes HDPE, Hypalon, Bituminous, EVA, PP, LLDPE, and PVC. Geomembranes are quite watertight when new, but continued effectiveness depends on resistance to both UV and mechanical damage. Effectiveness is estimated at 90 percent, based on the ponding tests. This value is slightly lower than geomembrane with concrete cover because of the potential for mechanical damage (animal traffic, equipment damage, and vandalism). Design life is predicted at 20 to 30 years because of the potential for mechanical and UV damage. The design life also varies depending of the UV resistance of the polymer and thickness of the geomembrane. Exposed geomembranes will require more maintenance than concrete linings. ***If not properly maintained, long-term effectiveness and service life can be drastically reduced.***

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

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