Geomembranes for Canal Lining

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ABSTRACT
Geomembranes are commonly used to control seepage from water canals. There are many types of geomembranes available for this application including PVC, HDPE, LDPE, CSPE, and EPDM geomembranes. Frequently these geomembranes require protection and there are several protection options including compacted soil, concrete, or shotcrete. The U.S. Bureau of Reclamation (USBR) has conducted a number of test programs on canal-lining systems including the Deschutes Canal-Lining Demonstration Project which involves the performance of 34 canal test-sections, many of which utilize geomembranes. Based on USBR and other test programs this paper examines the effectiveness of different types of geomembrane-based canal lining systems in terms of cost, seepage/leakage reduction, and long-term durability. Comparisons are made between the types of geomembrane used as well as the type of protective covering used (if any).

1. INTRODUCTION

Geomembranes have been used as water canal liners to control seepage since the 1950's and are an effective alternative to more traditional lining methods, such as concrete and compacted soil. One of the first uses of a geomembrane for a water canal was in 1954 for a U.S. Bureau of Reclamation (USBR) irrigation canal near Fort Collins, Colorado. The flexibility of geomembranes allows them to conform to the canal subgrade without puncturing and to adapt to subgrade changes with time. Geomembranes are also less pervious than concrete and compacted soil allowing for less loss of water over time. However, geomembranes are susceptible to damage from environmental and mechanical factors so various protective coverings have been used. Mechanical damage means damage to the geomembrane caused by people, animals, and/or equipment, whereas environmental damage refers to ultraviolet, wind, precipitation, etc. damage.

The USBR has extensive experience in the installation and monitoring of geomembranes for canal liners based on field test programs. The first such test program was started with a PVC test section on the Shoshone Project in Wyoming in 1957 (Morrison and Comer 1995). The USBR installed geomembrane linings in other canals and in 1991 began a canal-lining demonstration project on various canals branching from the Deschutes River (Haynes and Swihart 2002). The Deschutes Canal-Lining Demonstration Project is comprised of 34 test sections in Oregon, Idaho, Montana, and Oklahoma and was initiated to evaluate the effectiveness of a range of canal lining alternatives.

Traditionally, PVC geomembranes have been the geomembrane used for canal-lining projects. However, recently polyethylene (PE) based geomembranes (HDPE, LDPE, CSPE and VLDPE) as well as several other types of geomembranes (e.g. EDPM and polypropylene) have been used as canal liners.

All geomembranes are susceptible to damage from sun, wind, wave action, vegetation roots, and animal traffic, and thus must be protected. The most traditional method of protecting a geomembrane is to cover it with compacted soil. Another method is to cover the liner with concrete or shotcrete. The last option is to not protect the geomembrane and leave it exposed. Such exposed geomembranes may require special treatment and consideration to prevent damage.

This paper uses the Deschutes and other canal lining projects to examine the effectiveness of different geomembrane-based canal liners and protective liner systems based on cost, amount of seepage/leakage reduction, and long-term durability.

2. CASE HISTORIES

Tables 1 and 2 present the thickness, type of geomembrane installed, estimated cost (if available), seepage/leakage reduction due to the lining system, long-term durability, as well as references for the case history. The following paragraphs summarize the pertinent information for each of the case histories.

Table 1 – Summary of PVC and Polyethylene (PE) Canal Lining Case Histories

ID No.	Location/Section	Material	Date Installed	Cost (per m^2)	Seepage (m^3/m^2-day) [Reduction]	Status	Reference
PVC-1	Arnold Canal Section A-4	Exposed 0.75 mm PVC w/ geotextile UV cover	Mar-92	$11.30	0.012 [96%] in 1998	2002 - Some stiffening and cracking. Some seams above water table are separated.	Swihart and Haynes (2002)
PVC-2	Arnold Canal Section A-7	1.0 mm PVC w/ 3" grout filled mattress	Nov-91	$27.30	0.015 [95%] in 1998	2002 - A few small holes in mattress. Overall excellent	Swihart and Haynes
PVC-3	Helena Valley Canal	0.25 mm PVC w/ sand and gravel cover	1968	N/A	0.015 in 1983	1989 - Very good performance, some damage from animal hoves. 50% loss in plasticizer	Morrison and Comer (1995)
PVC-4	East Bench Canal	0.25 mm PVC w/ soil cover	1969	N/A	0.015 in 1974	1984 - Shows stiffening and 40% loss in plasticizer	Morrison and Comer
PVC-5	Bugg Lateral	0.25 mm PVC w/ soil cover	1961	N/A	N/A	1980 - Some stiffening and root penetration damage and 40% loss in plasticizer	Morrison and Comer (1995)
PVC-6	Main Canal	0.20 mm PVC w/ soil cover	1959	N/A	N/A	1991 - Significant stiffening has occurred. Field reports indicate still providing satisfactory seepage	Morrison and Comer (1995)
PVC-7	Fivemile Lateral	0.25 mm PVC w/ soil cover	1978	N/A	0.002 in 1983	1985 - Some small mechanical tears and holes. 12-30% plasticizer	Morrison and Comer
PVC-8	Black Sea Canal Section 1	0.25 mm PVC w/ sand and gravel cover	1977	N/A	[60%] in1978	1979 - Some soil sloughing	Timblin et al. (1984)
PVC-9	Black Sea Canal Section 2	0.25 mm PVC w/ concrete cover	1977	N/A	[81%] in 1978	1979 - Minor hairline cracking	Timblin et al. (1984)
PVC-10	Black Sea Canal Section 3	0.25 mm PVC w/ shotcrete cover	1977	N/A	[70%] in 1978	1979 - Some shrinkage cracking	Timblin et al. (1984)
PVC-11	Coachella Canal	0.75 mm PVC w/ concrete cover	1989	N/A	0.003 [98%] in 1994	1994 - No major problems	Kepler and Comer
PE-1	Arnold Canal Section A-1	0.10 mm PE geocomposite liner w/ shotcrete cover	Feb-92	$26.20	0.015 [95%] in 1997	2002 - Some small holes in shotcrete	Swihart and Haynes (2002)
PE-2	Arnold Canal Section A-2	0.75 mm textured VLDPE w/ 540 g/m^2 geotextile cushion	Oct-92	$27.10	0.034 [89%] in 1993	2002 - Only minor cracking found	Swihart and Haynes (2002)
PE-3	Arnold Canal Section A-3	Exposed 2.0 mm textured HDPE	Oct-92	$14.90	0.030 [90%] in 1997	2002 -Moderate stiifening and some small tears.	Swihart and Haynes
PE-4	Arnold Canal Section A-9	Exposed 1.5 mm VLDPE w/ 405 g/m^2 geotextile cushion	Nov-92	$19.30	0.021 [93%] in 1993	1995 - Removed from study due to whales in liner	Swihart and Haynes (2002)
PE-5	Arnold Canal Section A-10	Exposed 1.5 mm HDPE w/ 405 g/m^2 geotextile cushion	Nov-92	$19.30	0.021 [93%] in 1994	1995 - Removed from study due to whales in liner	Swihart and Haynes (2002)
PE-6	Ochoco Main Canal Section O-	Exposed 0.75 mm LLDPE	Nov-99	$8.40	0.003 [99%] in 2001	2002 - A few small tears from animal traffic	Swihart and Haynes
PE-7	Buffalo Rapids Section BU-1	Exposed 1.5 mm textured white HDPE w/ 338 g/m^2 Geotextile cushion	Apr-07	$13.60	N/A	2002 - Minimal problems	Swihart and Haynes (2002)
PE-8	South Canal Belle Fourche	0.75 mm VLDE w/ soil cover	Apr-87	N/A	N/A	1992 - No problems	Morrison and Comer
PE-9	Black Sea Canal Section 4	0.25 mm PE w/soil cover	1977	N/A	[30%] in1978	1979 - Some soil sloughing	Timblin et al. (1984)
PE-10	Black Sea Canal Section 5	0.25 mm PE w/ concrete cover	1977	N/A	[80%] in 1978	1979 - Minor hairline cracking	Timblin et al. (1984)
PE-11	Toshka Canal	1.5 mm textured HDPE w/ concrete	2003	N/A	N/A	2005 - No problems	Yazdani (2005)

Table 2 – Summary of Other Canal Lining Case Histories

ID No.	Location/Section	Material	Date Installed	Cost (per m^2)	Seepage (m^3/m^2-day) [Reduction]	Status	Reference
HYP-1	Arnold Canal Section A-5	Exposed 1.1 mm Hypalon w/ 540 g/m^2 geotextile cushion	Mar-92	$11.90	0.012 [96%] in 1998	2002 - Numerous large L-shaped tears	Swihart and Haynes (2002)
HYP-2	Arnold Canal Section A-6	Exposed 1.1 mm Hypalon w/ 270 g/m^2 geotextile cushion	Mar-92	$11.10	0.012 [96%] in 1999	2002 - Numerous large L-shaped tears	Swihart and Haynes (2002)
SPF-1	North Unit Canal Section NU-1	Spray-applied Polyurethane Foam (SPF) w/ Futura 500/550 Coating	Oct-92	$46.60	N/A	1998 - Half of the foam had washed out. Removed from study	Swihart and Haynes (2002)
SPF-2	North Unit Canal Section NU-2	SPF w/ Geothane 5020 Coating	Oct-92	$42.20	N/A	1998 - Half of the foam had washed out. Removed from study	Swihart and Haynes (2002)
SAG-1	North Unit Canal Section NU-3	Geoxtile w/ Spray-applied Geothane 5020 membrane	Oct-92	$14.90	N/A	Complete failure after first filling	Swihart and Haynes (2002)
SAG-2	North Unit Canal Section NU-4	Geoxtile w/ Spray-applied Geothane 5020 membrane	Oct-92	$19.30	N/A	Complete failure after first filling	Swihart and Haynes (2002)
GCL-1	Ochoco Main Canal Section O-1	Soil Covered Bentomat GCL	Apr-99	$8.83	0.033 [89%] in 2001	2002 - No problems	Swihart and Haynes (2002)
GCL-2	Ochoco Main Canal Section O-2	Exposed Bentomat GCL	Apr-99	$8.18	0.024 [92%] in 2001	2002 - Some crackng above waterline	Swihart and Haynes (2002)
GCL-3	Eberswalde Turnout	Riprap covered GCL	1997	N/A	N/A	2000 - No major problems	von Maubeuge et al. (2000)
EPDM-1	Ochoco Main Canal Section O-3	Exposed 1.1 mm EPDM w/ geotextile cushion on side slopes and soil on invert	Nov-99	$9.15	0.003 [99%] in 2001	2002 - No problems	Swihart and Haynes (2002)
EBG -1	Ochoco Main Canal Section O-5	Exposed 4.0 mm Coletanche NTP 2 ES elasometric bitumen geomembrane	Nov-00	$16.30	0.003 [99%] in 2001	2002 - No problems	Swihart and Haynes (2002)
EBG -2	Lugert-Altus West Canal Section LA-1	Exposed 4.0 mm Teranap elasometric bitumen geomembrane	May-94	$14.70	0.0 [100%] in 2002	2002 - Minor aligator cracking	Swihart and Haynes (2002)
EBG -3	Juniper Flat Main Ditch Section J-1	Exposed 4.0 mm Teranap elasometric bitumen geomembrane	Oct-97	$14.50	N/A	2002 - Minimal alligator cracking, several puntures from cow hooves	Swihart and Haynes (2002)

2.1 Canal Lining Projects

The following section provides background information on some of the larger canal test sections investigated during this study. Because of space constraints of all the test sections cannot be described.

2.1.1 Arnold Irrigation District – Main Canal – Bend, Oregon

The Arnold Main Canal is located several miles south of Bend, OR and diverts water from the Deschutes River about 11 km to the east. On average the canal is 20 m wide, 3 m deep, and has a flow capacity of about 4 m^3/s. The subgrade along the Arnold Canal consists primarily of fractured basaltic rock and a sandy-silty sediment. Subgrade preparation before geomembrane installation included the removal of loose rocks, boulders, and overhangs. Certain sections of the canal were also covered with 2 to 5 cm of soil. Canal-lining systems installed along the Arnold Canal include a 0.10 mm thick polyethylene (PE) geomembrane with a shotcrete cover, a 0.75 mm thick VLDPE geomembrane with a shotcrete cover, an exposed 2.0 mm thick HDPE geomembrane, an exposed 0.25 mm thick PVC geomembrane, a 1.0 mm thick PVC geomembrane with a grout mattress cover, and exposed 1.5 mm thick HDPE and VLDPE geomembranes. In short, a variety of geomembranes were tested in a similar environment which provides for a meaningful comparison of effectiveness and durability which is shown in Table 3. Table 3 shows PVC-1, PE-2, PE-4, PE-5, HYP-1, and HYP-2 are various geomembranes with only a geotextile as a protective cover or cushion. All of the geomembranes with a geotextile cover or cushion exhibit adequate seepage reduction, i.e. greater than 90%, but of these geomembranes only PVC-1 and PE-2 exhibited “good” long-term performance after 10 years of service although at different costs. The performance rating system is described subsequently.

Interestingly, PE-4 and PE-5 are 1.5 mm thick VLDPE and exhibited poor performance after 3 years while PE-2 is only 0.75 mm thick VLDPE and exhibited good performance after 10 years. Thus there may be variability in the performance of VLDPE canal lining systems. In addition, the two hypalon (CSPE) test sections did not perform well because their rating is “fair” after 10 years of service. PVC-2 and PE-1 both exhibited good long-term performance because they were protected with a concrete mattress and shotcrete, respectively.

Table 3 – Arnold Irrigation District Geomembrane Canal Lining Systems

ID No.	Thickness	Material	Cost (per m^2)	Seepage Reduction (%)	Rating at Time of Last Inspection	Service Life at Time of Last Inspection
PVC-1	0.75 mm	PVC w/ geotextile UV cover	$11.30	96%	Good	10 yr
PE-1	0.10 mm	PE geocomposite liner w/ shotcrete cover	$26.20	95%	Good	10 yr
PVC-2	1.0 mm	PVC w/ 3" grout filled mattress	$27.30	95%	Good	10 yr
PE-3	2.0 mm	Textured HDPE	$14.90	90%	Good	10 yr
PE-2	0.75 mm	VLDPE w/ 540 g/m^2 geotextile cushion	$27.10	90%	Good	10 yr
HYP-1	1.1 mm	Hypalon w/ 540 g/m^2 geotextile cushion	$11.90	96%	Fair	10 yr
HYP-2	1.1 mm	Hypalon w/ 270 g/m^2 geotextile cushion	$11.10	96%	Fair	10 yr
PE-4	1.5 mm	VLDPE w/ 405 g/m^2 geotextile cushion	$19.30	93%	Poor	3 yr
PE-5	1.5 mm	VLDPE w/ 405 g/m^2 geotextile cushion	$19.30	93%	Poor	3 yr

2.1.2 Black Sea Canal – Romania

The Black Sea Canal is located in Eastern Romania. These test sections are part of a US – USSR joint study on Plastic Films and Stabilizers. On average the canal is 12 m wide, 2 m deep with 2H:1V side slopes. The test sections installed are a 0.25 mm thick PVC geomembrane with soil, concrete, and shotcrete covers, and a 0.25 mm thick PE geomembrane with soil and shotcrete covers (Timblin et al. 1984).

2.1.3 Toshka Canal – Egypt

The Toshka Canal is located South Valley of Egypt and diverts water from Lake Nasser to the Western Desert. The canal is 30 m wide, 8 m deep with 2H:1V side slopes. The typical flow in the Toshka Canal is about 100 m^3/s. Starting in 2003, as part of the South Valley Project, the Golden Trade Company of Cairo began installing a 1.5 mm thick textured HDPE liner protected by 100 mm of soil-cement mixture and 200 mm of concrete (Yazdani, 2005).

2.1.4 Eberswalde Turnout – Germany

The Eberswalde Turnout is a boat turning basin located near the town of Eberswalde, Germany. The canal is 48 m wide, 4 m deep with 3H:1V side slopes. The canal was lined in 1997 with a needle-punched GCL protected by a sandmat and a 300 mm thick layer of riprap. All installation was performed without dewatering the canal (von Maubeuge et al. 2000).

3. COMPARISON OF CANAL LINING SYSTEMS

Tables 4 through 6 present a comparison of the geomembranes and protective systems collected and studied herein. The geomembrane based liner systems are divided into the following three groups:

1.) Concrete/shotcrete covered geomembranes – Liner systems that incorporate a concrete or shotcrete layer over the geomembrane for environmental and physical protection (see Table 4).

2.) Exposed geomembranes – Liner systems in which the geomembrane is left exposed without any protective cover (see Table 5).

3.) Soil covered – Liner systems where a layer of compacted soil is placed over the geomembrane for environmental and physical protection (see Table 6).

The performance rating for each system describes the condition of the geomembrane at the time of its last inspection. This geomembrane rating is independent of cost, seepage reduction, and time of last inspection. The rating system is as follows:

1.) Good – Geomembrane is still in good to excellent condition. Little maintenance has been required to date and the geomembrane is still of high quality.

2.) Fair – Geomembrane is in adequate condition. Some maintenance has been required to date because the geomembrane has experienced tears, punctures, or signs of significant stiffening.

3.) Poor – Geomembrane is in poor condition. Major repairs have been required to date, or the liner completely failed and/or was taken out of service.

The following paragraphs compare the performance of different geomembrane based lining systems shown in Tables 4 through 6 based on type of geomembrane, protective layer over the geomembrane, cost, seepage/leakage reduction, and long-term durability.

Table 4 - Concrete/Shotcrete Covered Geomembrane Canal Lining Systems

ID No.	Thickness	Material	Cost (per m^2)	Seepage Reduction (%)	Geomembrane Rating at Time of Last Inspection	Service Life at Time of Last Inspection
PE-1	0.10 mm	PE geocomposite liner w/ shotcrete cover	$26.20	95%	Good	10 yr
PVC-9	0.25 mm	PVC w/ concrete cover	N/A	81%	Good	1 yr
PVC-10	0.25 mm	PVC w/ shotcrete cover	N/A	70%	Good	1 yr
PE-10	0.25 mm	PE w/ concrete cover	N/A	80%	Good	1 yr
PE-2	0.75 mm	VLDPE w/ 540 g/m^2 geotextile cushion	$27.10	90%	Good	10 yr
PVC-11	0.75 mm	PVC w/ concrete cover	N/A	98%	Good	5 yr
PVC-2	1.0 mm	PVC w/ 3" grout filled mattress	$27.30	95%	Good	10 yr
PE-11	1.5 mm	PE w/ concrete cover	N/A	N/A	Good	2 yr

Table 5 – Exposed Geomembrane Canal Lining Systems

ID No.	Thickness	Material	Cost (per m^2)	Seepage Reduction (%)	Geomembrane Rating at Time of Last Inspection	Service Life at Time of Last Inspection
PVC-1	0.75 mm	PVC w/ geotextile UV cover	$11.30	96%	Good	10 yr
PE-6	0.75 mm	LLDPE	$8.40	99%	Good	2 yr
HYP-1	1.1 mm	Hypalon w/ 540 g/m^2 geotextile cushion	$11.90	96%	Fair	10 yr
HYP-2	1.1 mm	Hypalon w/ 270 g/m^2 geotextile cushion	$11.10	96%	Fair	10 yr
EPDM-1	1.1 mm	EPDM w/ geotextile cushion on side slopes and soil on	$9.15	99%	Good	3 yr
SPF-1	1.25 mm	SPF w/ Futura 500/550 Coating	$46.60	N/A	Poor	5 yr
SPF-2	1.25 mm	SPF w/ Geothane 5020 Coating	$42.20	N/A	Poor	5 yr
PE-4	1.5 mm	VLDPE w/ 405 g/m^2 geotextile cushion	$19.30	93%	Poor	3 yr
PE-5	1.5 mm	HDPE w/ 405 g/m^2 geotextile cushion	$19.30	93%	Poor	3 yr
PE-7	1.5 mm	Textured white HDPE w/ 338 g/m^2 Geotextile cushion	$13.60	N/A	Good	1 yr
SAG-1	1.5 mm	Geoxtile w/ Spray-applied Geothane 5020 membrane	$14.90	N/A	Poor	1st Filling
SAG-2	1.5 mm	Geoxtile w/ Spray-applied Geothane 5020 membrane	$14.30	N/A	Poor	1st Filling
PE-3	2.0 mm	Textured HDPE	$14.90	90%	Good	10 yr
EBG -1	4.0 mm	Coletanche NTP 2 ES elasometric bitumen geomembrane	$16.30	99%	Good	2 yr
EBG -2	4.0 mm	Teranap elasometric bitumen geomembrane	$14.70	100%	Good	8 yr
EBG -3	4.0 mm	Teranap elasometric bitumen geomembrane	$14.50	N/A	Good	5 yr
GCL-2	N/A	Bentomat GCL	$8.18	92%	Good	3 yr

Table 6 – Soil Covered Geomembrane Canal Lining Systems

ID No.	Thickness	Material	Cost (per m^2)	Seepage Reduction (%)	Geomembrane Rating at Time of Last Inspection	Service Life at Time of Last Inspection
PVC-6	0.20 mm	PVC	N/A	N/A	Fair	21 yr
PVC-4	0.25 mm	PVC	N/A	N/A	Good	14 yr
PVC-5	0.25 mm	PVC	N/A	N/A	Fair	19 yr
PVC-8	0.25 mm	PVC	N/A	60%	Good	1 yr
PE-8	0.25 mm	PE	N/A	30%	Good	1 yr
PVC-7	0.25 mm	PVC	N/A	N/A	Good	15 yr
PE-9	0.75 mm	VLDPE	N/A	N/A	Good	15 yr
GCL-1	N/A	Bentomat GCL	$8.83	89%	Good	3 yr
GCL-3	N/A	GCL w/ Riprap cover	N/A	N/A	Good	3 yr

3.1 Type of Geomembrane

Figures 1 and 2 present the ranges in cost and seepage reduction percentage, respectively, for the exposed geomembranes examined herein. The range in cost for exposed geomembranes is significant because it reflects the installed cost of the geomembrane because no protective layer is used. Figure 1 shows a large cost range for PE geomembranes which reflects the use of different geomembrane thicknesses. Figure 1 also shows the geomembranes with the lowest cost are EPDM and PVC with Hypalon being slightly higher. Figure 2 shows the highest seepage reduction for EPDM and bitumen lining systems. The PE geomembranes show a range in seepage reduction from 90% to 99% while PVC and Hypalon show a similar reduction (~96%) for the cases considered. In summary, all of the geomembranes show a high percentage (≥90%) of seepage reduction.

Figure 3 shows the range of service life for the exposed geomembranes considered herein. The points labeled lower bound (solid triangles) represent the longest service life reported for which the type of geomembrane was rated good. Thus, the lower bound values represent a minimum service life because they are still performing well and the service life is controlled by the length of the study. The points labeled upper bound (solid circles) represent the service life reported at which the geomembrane was rated fair or poor because the geomembrane was already performing fair or poorly at the time. Figure 3 shows that PVC and PE geomembranes have the highest upper bound service lives. However, two of the PE cases examined have a lower bound service life of only three years. EPDM and bitumen geomembranes have upper bound service lives of three and eight years, respectively, but these durations could be greater if the geomembranes continue to perform adequately as the study continues.

In summary, PVC and PE are the two most commonly used geomembranes for canal liners and thus have been in service the longest. The data herein suggest no significant difference between these two materials in terms of leakage reduction (>90%) or durability. For comparison purposes, concrete and shotcrete liners provide a seepage reduction of only about 70% (Swihart and Haynes 2002). PVC geomembranes have shown excellent long-term durability with an exposed service life of 10 years with a good rating for an exposed 0.75 PVC mm thick liner. PE geomembranes have also shown good durability including a 10 year old, 2 mm thick textured HDPE liner in an exposed application. However, the PVC geomembranes generally range in thickness from 0.25 mm to 0.75 mm, whereas the PE geomembranes generally range from 0.75 mm to 2 mm thick for canal linings. An increase in thickness generally results in an increase in durability and cost, but does not result in a reduction of the water seepage/leakage from the canal.

Four cases where spray-applied geomembranes were used as canal liners were also evaluated. In each of these cases, the spray-applied geomembrane was washed out of the canal within five years. Installation of the spray-applied membranes also was more expensive than conventional geomembranes. Thus, spray-applied geomembranes do not appear to be viable for canal linings.

Other geomembranes examined are Hypalon, EPDM, and elasometric bitumen for exposed canal linings. Both Hypalon geomembrane installations developed large L-shaped tears during the first 10 years of service. The Hypalon liners were used in an exposed application which contributed to the decrease in service life. The EPDM geomembrane provided excellent seepage reduction and has exhibited few problems in 3 years of service in an exposed application. The three elasometric bitumen geomembrane showed only minor alligator cracking after 3, 5, and 8 years of exposed service and show a reduction in seepage of 99% and 100% from the pre-liner seepage. In summary, the EPDM and bitumen liners show promise as canal liners but have not been subjected to exposure times as long as PVC and PE geomembranes.

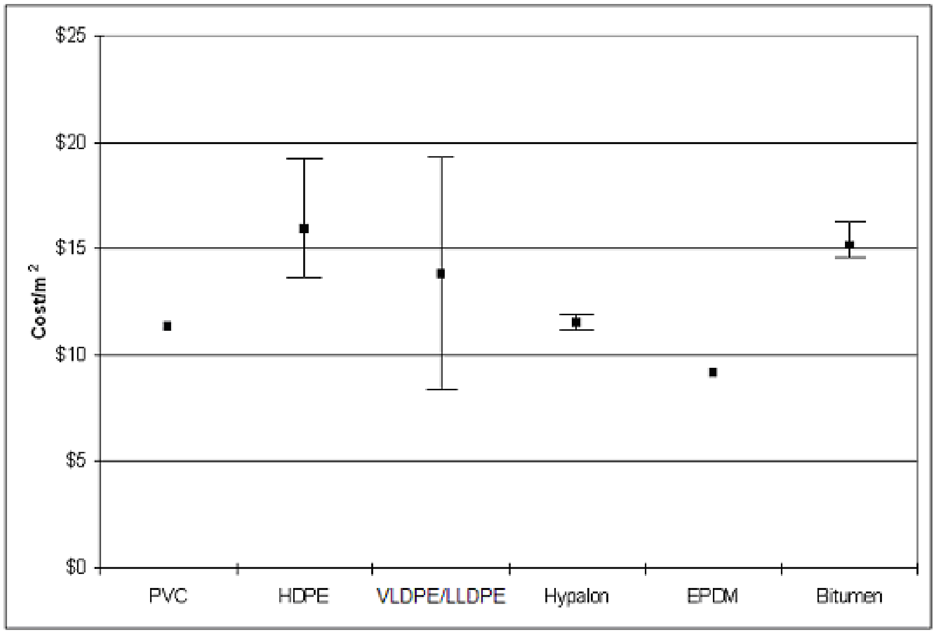

Figure 1 – Range in Cost for Exposed Geomembrane Liners

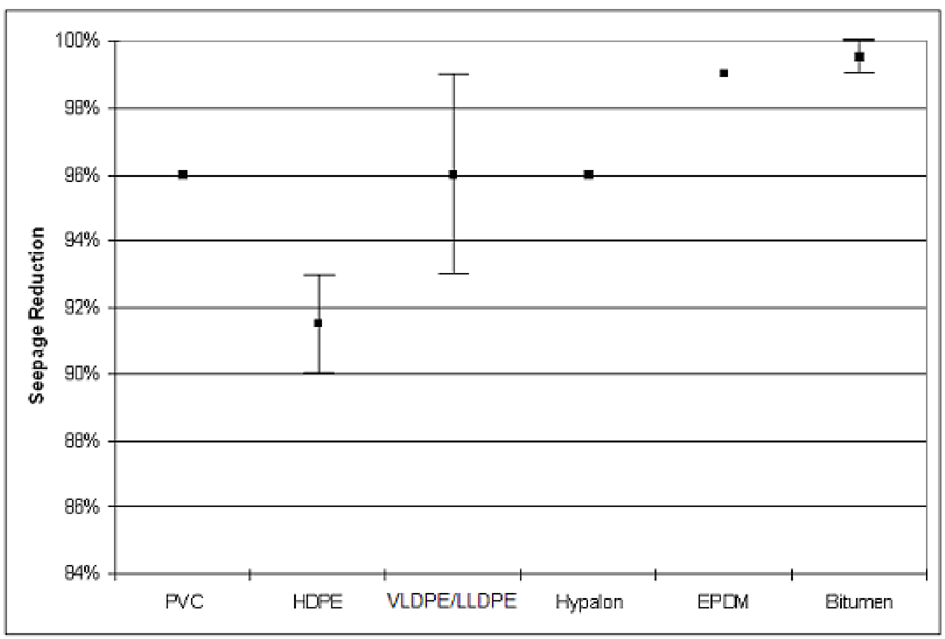

Figure 2. Range in Seepage Reduction for Exposed Geomembrane Liners

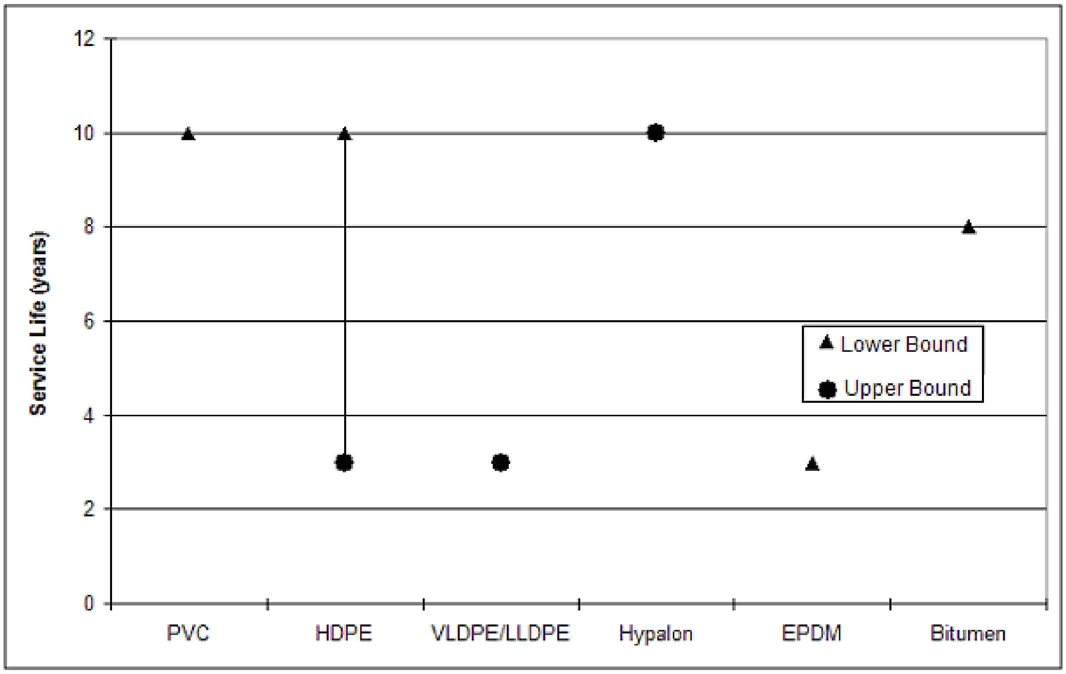

Figure 3. Range in Service Life for Exposed Geomembrane Liners

3.2 Type of Protective Cover

The use of a protective cover for the geomembrane is always an additional cost when compared to an exposed geomembrane. Using a concrete or shotcrete cover for the geomembrane can increase the cost of liner installation by up to 100%. Although no cost data is available for a soil covered liner system, the costs of overexcavating, placing, and compacting soil on top of the geomembrane represents a significant increase over an exposed geomembrane.

A protective cover usually has little effect on the seepage/leakage reduction of a geomembrane-based liner system so the main purpose of the cover is to reduce geomembrane exposure to the environment and physical damage. Concrete/shotcrete covered geomembranes usually exhibit a slightly higher seepage reduction percentage than exposed or soil covered geomembranes, as seen in cases PE-1 and PVC-2.

The use of a concrete/shotcrete cover can greatly extend the expected service life of a geomembrane (Swihart and Haynes 2002). A concrete or shotcrete cover essentially protects the geomembrane from physical and environmental damage. The use of a soil protective cover increases the durability of the liner system but not as much as a concrete/shotcrete cover. Soil covers also frequently have stability problems on side slopes of a canal but are usually less expensive then concrete/shotcrete covers. Generally soil covers are stable with side slopes that are less than or equal to 3H:1V.

By comparison, exposed geomembranes vary in their effectiveness while all covered geomembranes have performed well. All exposed geomembranes have provided adequate seepage reduction while the geomembrane was intact. Six of the exposed geomembranes either failed or were taken out of service due to leakage problems. For comparison, PVC-1 and PE-3 cases are rated good at a service life of 10 years, and PE-6 is rated good at a service life of 2 years even though they are exposed. In contrast, all of the covered geomembranes have not exhibited leakage problems.

4. NEW DEVELOPMENTS

A new alternative non-geomembrane lining system is a bentonite coated aggregate composite (AquaBlok®) which is used extensively for capping contaminated sediments in place, i.e. through a column of water. This material essentially consists of an aggregate core encapsulated with bentonite and proprietary performance enhancers. Bentonite coated aggregate composites are gaining acceptance in a wide range of sealing applications such as, anti-seep collars for piping, sealing dams and ponds, annular seals in wells, and as a canal lining material.

This is a new material for canal lining that does not currently have sufficient installation data for inclusion in the tables and graphs presented herein. However, the material has been extensively tested for Superfund projects and is used in many other sealing related applications. Barriers made of the bentonite coated aggregate are typically applied without draining the water/liquid from the impoundment, can be constructed using conventional equipment, routinely achieves hydraulic conductivities in the 10^{-8} cm/s range, and have been shown to be resistant to stream velocities up to approximately 1.5 m/sec.

5. CONCLUSIONS

This paper summarizes thirty-five case histories in which geomembranes have been used in canal liner system. Based on these cases, the following conclusions can be drawn:

(1) Geomembranes are well suited for use as water canal liners. Lining a canal with a geomembrane reduces the seepage from the canal by at least 90% for the geomembranes considered herein even if the geomembrane is exposed.

(2) There is no evidence herein to suggest a difference in the effectiveness/seepage reduction between PVC and PE; the two most commonly used geomembranes for canal lining systems.

(3) The case histories used herein show that placing a concrete or shotcrete cover over the geomembrane increases the durability of the liner system but also greatly increases the cost. The type of geomembrane is of little importance when a concrete or shotcrete cover is used because the geomembrane is not susceptible to most potential sources of physical and environmental damage. Thus, the geomembrane should be selected solely based on cost when a concrete/shotcrete cover is used because all geomembranes exhibit good seepage leakage control.

(4) Spray-applied geomembranes do not appear to be a viable option for water canal liners because all such test sections failed shortly after installation. In each of these case, the spray-applied material was washed away by the water flow. EDPM and elasometric bitumen geomembranes appear to be well suited for use as canal liners but long-term data is not available for these materials.

(5) Exposed geomembranes can be cost-effective and have performed well in several cases. However, in several cases exposed geomembranes suffered enough physical and/or environmental damage that made them ineffective.

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