Full-Scale Laboratory Testing of a Toe Drain with a Geotextile Sock

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by
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U.S. Department of Interior
Bureau of Reclamation
Dam Safety Office

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Executive Summary

This report describes the full-scale laboratory testing (pipe box testing) of a 15-inch-diameter, corrugated, polyethylene toe drain with a knitted geotextile sock, backfilled with a sand envelope material. The test results are compared with previous small-scale and full-scale tests using perforated pipe with 1/8-inch and 1/4-inch perforations, but no geotextile. Use of the geotextile optimized toe drain performance both with respect to flow and with respect to loss of the sand envelope. The long-term flow rate was 21 gpm per linear foot of pipe, which was significantly higher (by a factor of 3 to 12) than the earlier tests without geotextile. The total loss of sand envelope was only 50 grams per linear foot of pipe, which was significantly lower (by a factor of 4 to 17) than the earlier tests without geotextile. The test with geotextile was run for 31 days at a constant head of 2½ feet above the pipe invert with no indication of clogging. The results from this test with geotextile along with the two previous tests without geotextile are summarized below:

Test Configuration	Flow Rate (gpm / lin ft)	Envelope Loss (grams / lin ft)	Test Duration and Comments
1/8-inch slots	1.74 Not Stable	200 Stable	8 Days - Not Stable
1/4-inch holes	6.3 Not Stable	850 Not Stable	24 Days - Not Stable
Geotextile Sock	21.3 Stable	50 Stable	31 Days - Stable
Improvements with Geotextile (factor)	3 to 12	4 to 17	

Based on these results, use of geotextile sock in conjunction with a sand envelope is recommended for all future toe drain installations in areas with fine native soils. Use of the geotextile sock will improve toe drain performance by increasing flow rates and decreasing loss of envelope material. The experience gained with the use of geotextiles in toe drains will also improve Reclamation's ability to use geotextiles in other applications.

A traditional 2-stage filter (consisting of a gravel filter surrounded by a sand filter) is sometimes used in problem areas with fine native soils. However, traditional 2-stage filters are difficult and expensive to construct. Use of a geotextile as one stage of the 2-stage filter solves the constructability problem.

Future Studies - The poor performance of the sand envelope at Lake Alice Dam was not anticipated. The dramatic improvement in performance with the addition of the geotextile sock was equally surprising. These results raise questions about whether similar improvements would be seen by using a geotextile sock with a traditional gravel envelope . Additional testing is required to evaluate the performance of a gravel envelope both with and without a geotextile sock.

Full-Scale Laboratory Testing
of a Toe Drain with a Geotextile Sock

Background - Reclamation's traditional drain design (both agricultural drains and toe drains below dams) uses a gravel envelope around corrugated perforated pipe with slotted or circular perforations. Our gradation limits for gravel envelopes are shown in Appendix A *(US Bureau of Reclamation, 1993)*. The perforations in the drain pipe (both slotted and circular perforations) must meet Reclamation's perforation criteria of Perforation size < ½D_{85} *(US Bureau of Reclamation, 1987)*. Appendix B shows that our perforation criteria generally agrees with other published criteria *(Vlotman)*. However, previous tests *(Swihart)* have shown that this perforation criteria (when used with a sand envelope) only addresses retention of envelope material, but not flow rate or clogging. Therefore, use of a geotextile sock was investigated with hopes of both increasing flow rates and decreasing loss of envelope material.

Note - A traditional 2-stage filter (consisting of a gravel filter surrounded by a sand filter) is sometimes used in areas with fine native soils. However, traditional 2-stage filters are difficult and expensive to construct. Use of a geotextile as one stage of the 2-stage filter solves the constructability problem.

Previous Testing - In 1997, a total of 2,136 linear feet of 18- and 24-inch toe drain were installed at Lake Alice Dam near Scottsbluff Nebraska. Because of the fine silty native soils, a sand envelope was specified. The pipe was specially perforated with 1/8-inch circular perforations to match the D_{85} of the sand envelope (Perforation Size = ½D_{85}). However, within a few weeks, most of the 1/8-inch perforations had plugged with sand particles. Small-scale laboratory tests *(Szygielski)* showed that both 1/8-inch circular perforations and 1/8-inch slotted perforations were prone to clogging with the sand envelope material. Two full-scale tests were performed using the sand envelope with 1/8- and 1/4-inch perforations. The perforation open area for both tests was held constant at 4.0 in^2 per linear foot.

The first test with the 1/4-inch circular perforations demonstrated a decreasing flow rate with time (indicating clogging). After 24 days, the flow rate had decreased by 24% to 6.3 gpm per linear foot, which was only about half the desired flow rate of 12 gpm per foot. The 1/4-inch perforations also showed extensive loss of envelope material, losing almost 2 pounds (850 grams) of sand envelope per linear foot of pipe. The test results are shown in figure 1.

The second test with 1/8-inch slotted perforations also demonstrated decreasing flow rate with time (again indicating clogging). After only 8 days, the flow rate had decreased by 43% to 1.7 gpm per linear foot, which was far below the desired flow rate of 12 gpm per foot. The 1/8-inch slotted perforations did demonstrate adequate retention of the sand envelope, losing only 200 grams of envelope material per linear foot. The test results for the 1/8-inch slotted perforations are shown in figure 2.

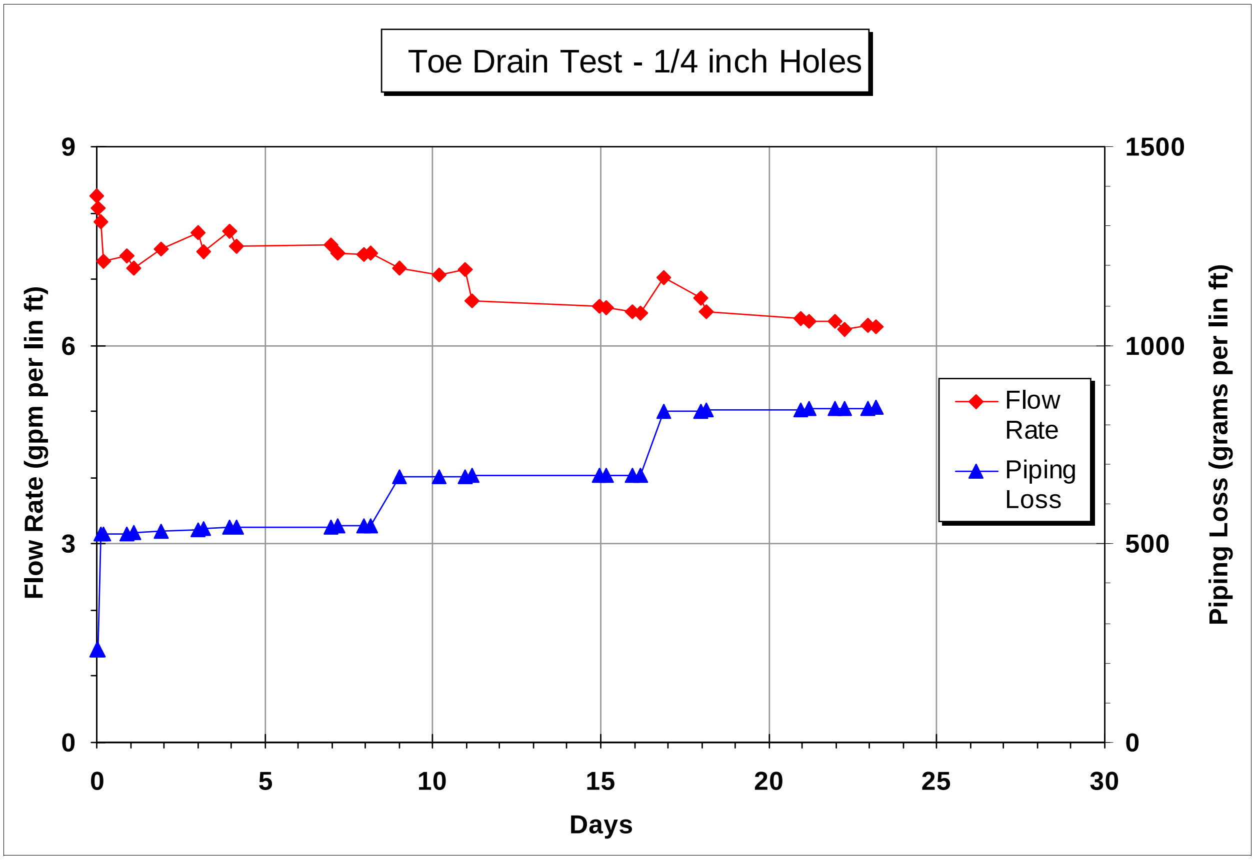

Figure 2 – Results from previous toe drain test with 1/4 inch circular perforations - no geotextile.

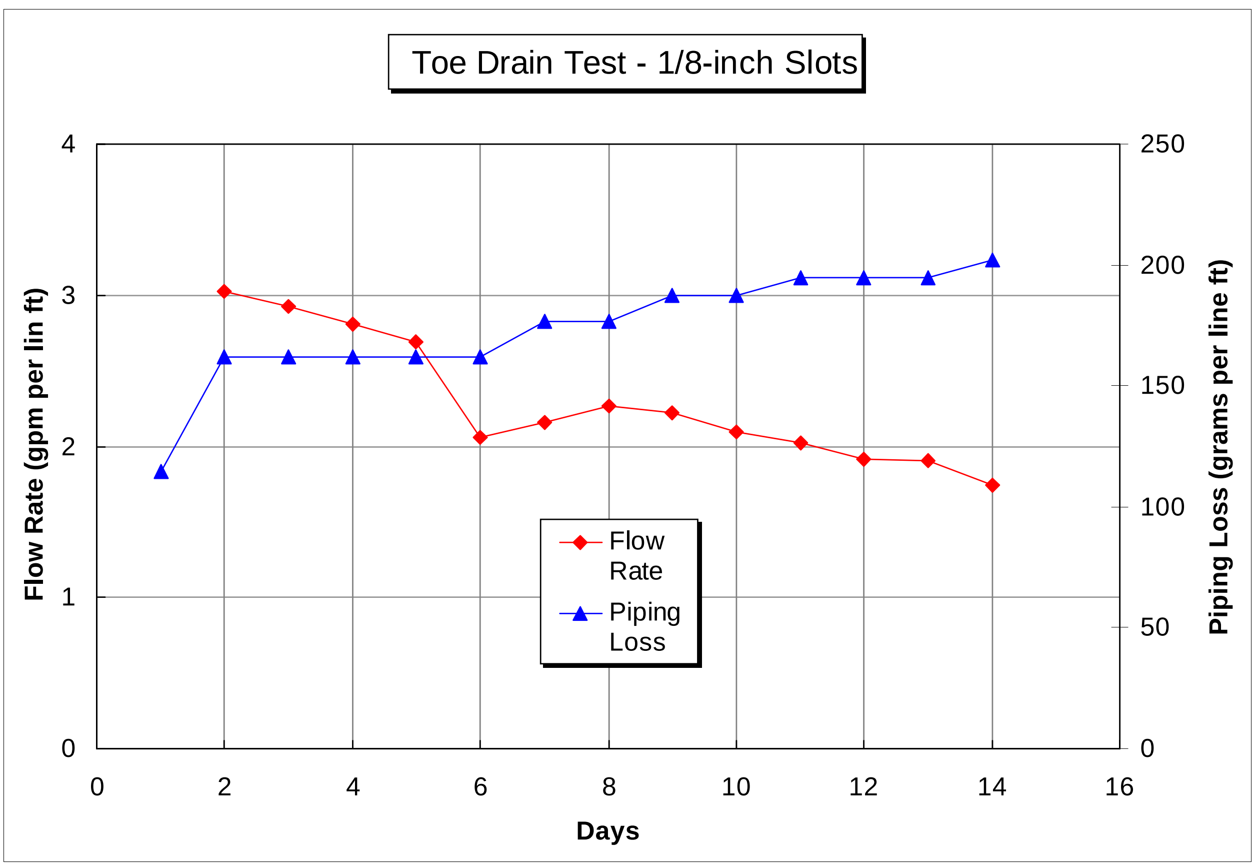

Figure 1 – Results from previous toe drain test with 1/8 inch slotted perforations - no geotextile.

Test Apparatus - The test apparatus (pipe box) for testing the drain pipe covered with a geotextile sock is shown in Figures 3 and 4. The nominal box dimensions are 4- by 4- by 3-ft (height by width by length). The drain pipe measures 5-ft long, and the length of pipe covered with geotextile inside the test box is 28.8 inches (2.40 feet). As shown in the figures, water is pumped out of the sump in the floor drain, and into the 2-inch diameter PVC standpipes. The standpipes are connected to a PVC well screen network located around the bottom perimeter inside the box. The water flows out of the PVC well screen, upward through the sand envelope, through the geotextile, through the pipe perforations, and into the drain pipe. The lower half of one end of the drain pipe is blocked-off, forcing all the water to flow out the opposite end, where it is sieved for particle size analysis, and metered through an exit flowmeter. The outflow water is then returned to the floor drain for recirculation. The water level in the box is maintained at a constant head (2.5 feet above the pipe invert) by overflows located on each corner of the box. Overflow water is again returned to the floor drain for recirculation.

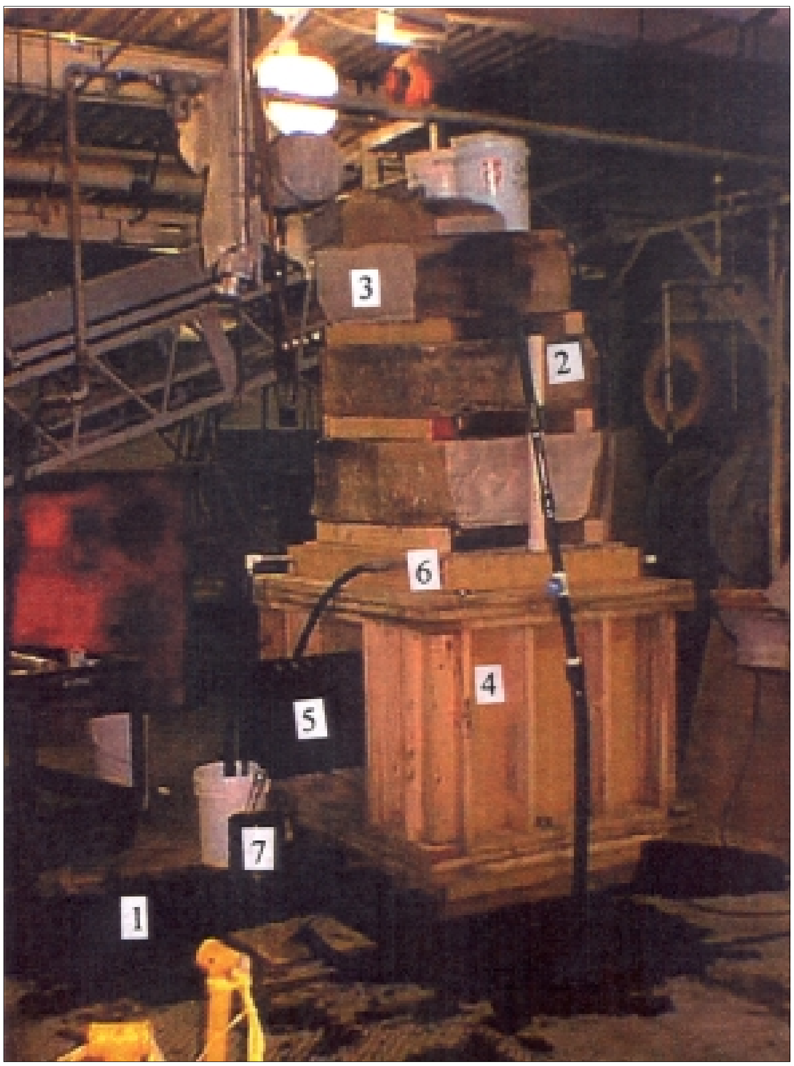

Figure 3 – Pipe box test apparatus includes a pump in the floor sump (1), standpipes (2), ballast (3), pipe box (4), drain pipe (5), overflows (6), and outflow sieves (7).

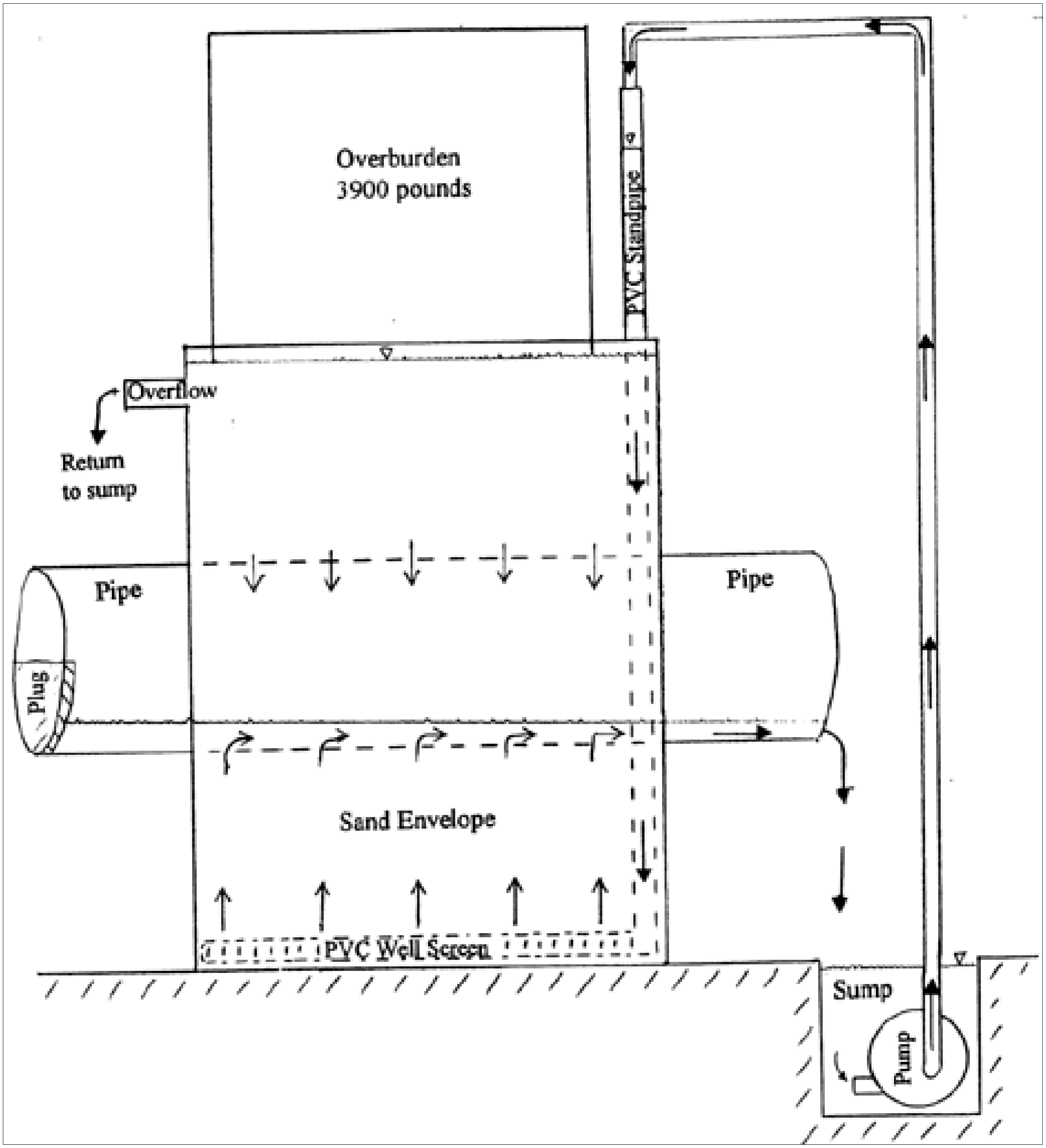

Figure 4 – Schematic of the test apparatus - Water is pumped out of the floor sump and into the 2-inch PVC standpipes. The standpipes are connected to a PVC well screen network located around the bottom perimeter inside the box. The water flows through the slotted pVC well screen, upward through the sand envelope, through the geotextile, through the pipe perforations, and into the drain pipe. The lower half of one end of the drain pipe is blocked off forcing all the water to flow out the opposite end, where it is sieved and/or metered (flow meter) before returning to the flow drain for recirculation. Water that overflows the pipe box is also collected and returned to the floor drain.

Test Set-up- A 15-inch-diameter dual-wall pipe with 5/16-inch diameter perforations and 2.1 in² open area per linear foot (66 perforations in 2.4 linear feet) was selected for testing (Note that the two previous tests had a much larger open area at 4.0 in² per linear foot). The geotextile sock is a knitted fabric from Cariff Corporation with AOS = #30 sieve. The manufacturers data sheet for the geotextile is included in Appendix C.

The pipe box was backfilled with the same sand envelope material used in the previous tests. The envelope gradation is shown in Figure 5 along with the specification limits from Lake Alice Dam. The sand envelope was placed in about 6-inch lifts, and each lift was sluiced into place by flooding with water at about 25 gpm. Sand envelope that washed into the pipe through the geotextile was collected, weighed, and sieved. The box was backfilled flush to the top, and the average in-place density was calculated at 109 pcf (4031 lbs / 36.9 ft^3). The box was then loaded with 3900 pounds of ballast to simulate a total earth cover of about 4½ feet over the pipe. Typical backfill and sluicing operations are shown in figures 6 through 8. As in the previous two tests, the important test criteria were adequate flow, potential plugging of geotextile (clogging), and excessive loss of envelope material.

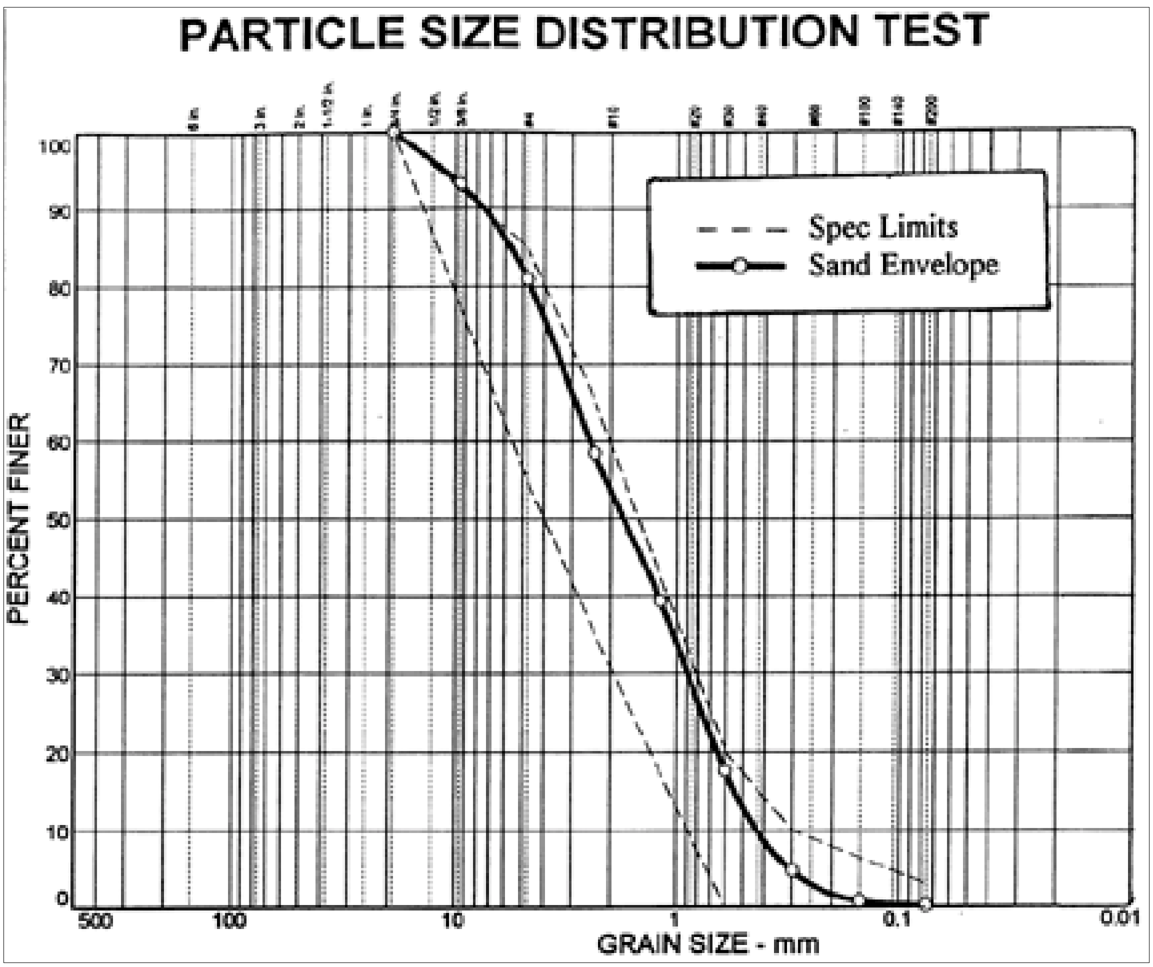

Figure 5 – Gradation of Sand Envelope Material.

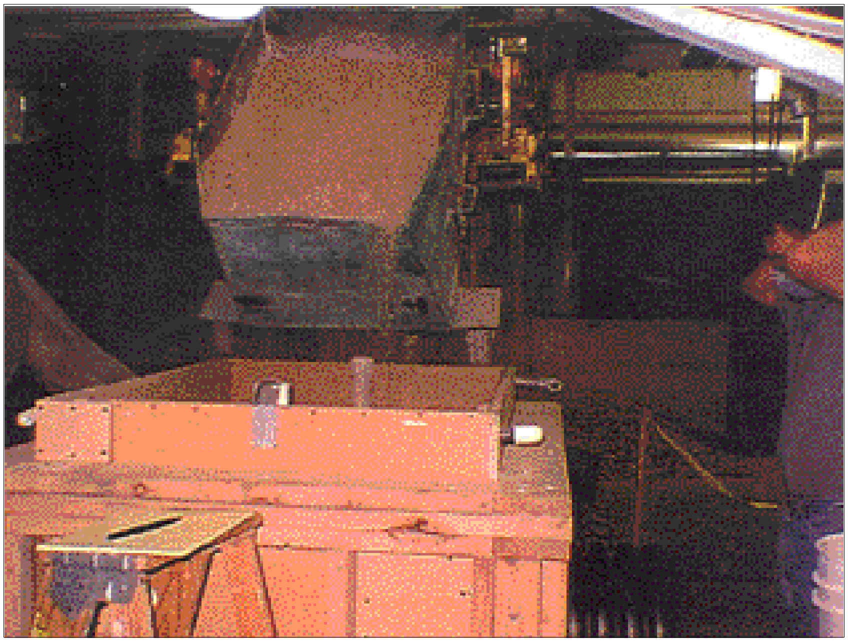

Figure 7 – Special forklift used to dump “boats” of sand envelope into pipe box.

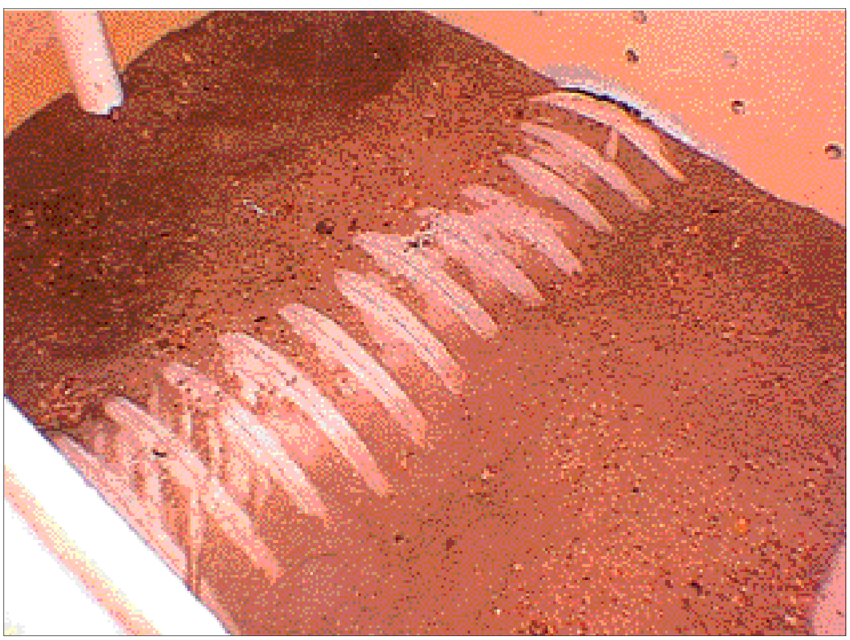

Figure 6 – View of pipe box interior with partial backfill. Length of drain pipe covered with geotextile is 28.8 inches. The 2-inch PVC standpipes deliver water to the PVC well-screen distribution network around the inside bottom perimeter of the pipe box.

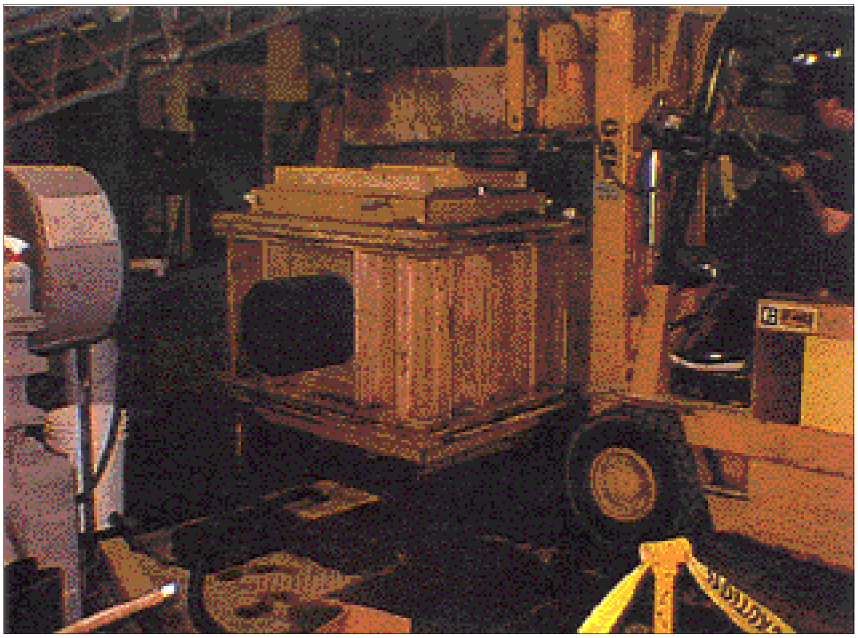

Figure 8 – 3900 pounds of ballast were loaded onto the test box to simulate 4 to 5 feet of earth cover.

Outflow Data - All the testing (this test and the previous two tests) were performed under constant head conditions. To achieve the desired head (2½ feet above the pipe invert), a total flow rate of about 55 gpm (23 gpm per linear foot) was required. To achieve that flow rate, two pumps were used, and the water inflow was slowly ramped-up over a 3-day period. Once established, the flow rate and head were maintained throughout the 31-day test duration. Outflow measurements were typically taken twice a day using a 2-inch flowmeter. In addition, the outflow was continuously sieved to collect any envelope material washing through the geotextile and pipe perforations. Typical water flow through the geotextile and 5/16-inch circular perforations is shown in figure 9. After peaking at about 23 gpm per foot, the outflow stabilized at about 21 gpm per linear foot with no indication of clogging. This flow rate is almost twice the desired flow rate of 12 gpm per linear foot. The test results are shown in table 1, and plotted in figure 10.

Figure 10 – All the 5/16-inch diameter perforations are abundantly flowing water. Flow rate is approximately 56 gpm (23 gpm per linear foot of drain pipe).

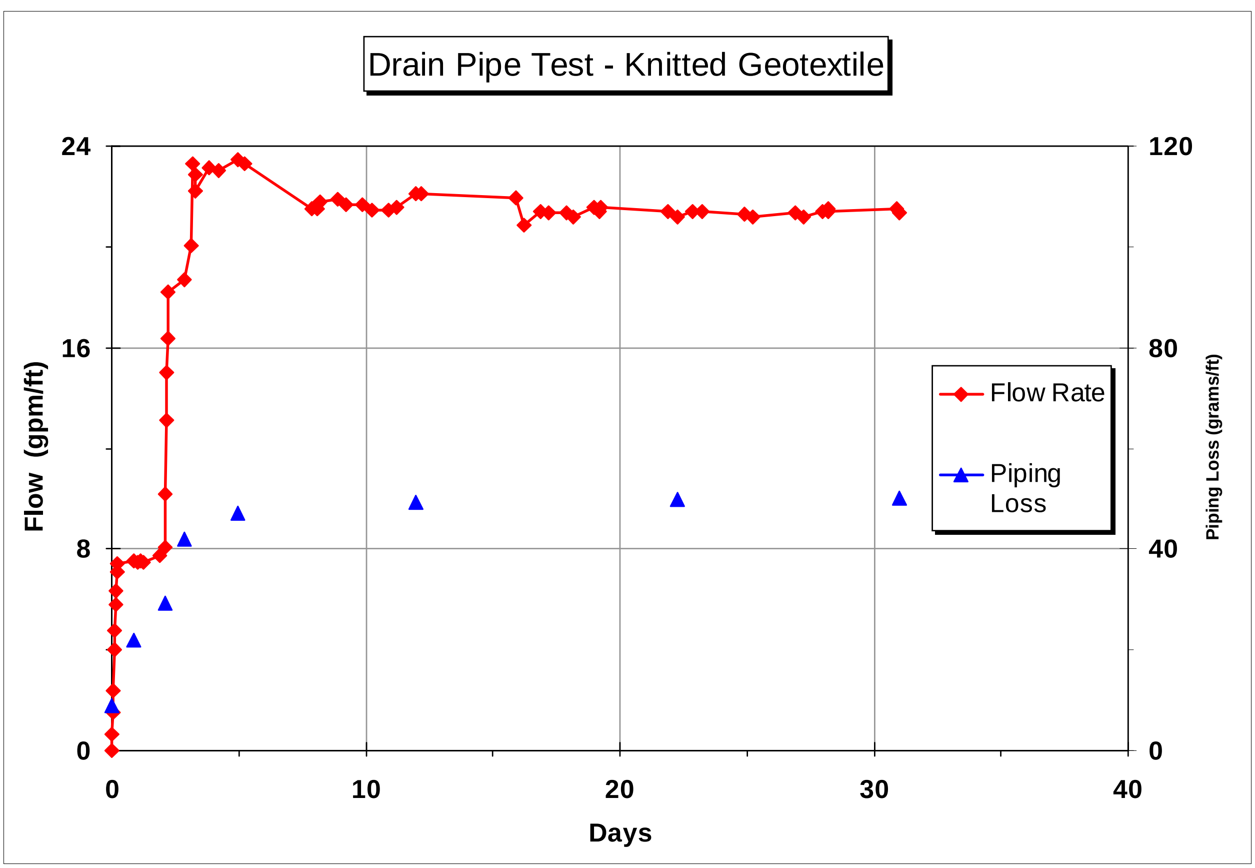

Figure 9 – Geotextile Sock Test - Outflow and Envelope Loss Data

Table 1 - Outflow Data - Normalized for 1-ft. unit length of pipe.

Test Duration (days)	Raw Data			**Normalized Data**		Comments
	Outflow (gpm)	Envelope Loss (grams)		**Outflow (gpm/ft)**	**Cumulative Envelope Loss (grams/ft)**	
		Daily	Cumulative			
0.00	0	21.3	21.3	**0**	**8.9**	Sluicing Loss Start Test
0.02	1.6			**0.7**		
0.03	3.6			**1.5**		
0.07	5.7			**2.4**		
0.10	9.6			**4.0**		
0.13	11.5			**4.8**		
0.15	13.9			**5.8**		
0.17	15.2			**6.3**		
0.19	17.0			**7.1**		
0.21	17.8			**7.4**		
0.88	18.1	31.6	52.9	**7.5**	**22.0**	
1.05	18.0			**7.5**		
1.13	18.0			**7.5**		
1.25	17.9			**7.5**		
1.88	18.6			**7.7**		
2.08	19.4	17.0	69.9	**8.1**	**29.1**	
2.10	24.4			**10.2**		
2.15	31.5			**13.1**		
2.17	36.0			**15.0**		
2.19	39.3			**16.4**		
2.21	43.7			**18.2**		
2.85	44.9	30.7	100.6	**18.7**	**41.9**	
3.10	48.1			**20.0**		
3.19	55.9			**23.3**		Reached Full Flow
3.28	54.9			**22.9**		
3.29	53.3			**22.2**		
3.85	55.5			**23.1**		
4.19	55.2			**23.0**		
4.96	56.3	12.2	112.8	**23.5**	**47.0**	
5.24	55.9			**23.3**		
7.88	51.6			**21.5**		
8.09	51.6			**21.5**		
8.22	52.3			**21.8**		
8.88	52.5			**21.9**		
9.22	52.0			**21.7**		
9.88	52.0			**21.7**		
10.22	51.5			**21.5**		
10.88	51.5			**21.5**		
11.19	51.8			**21.6**		
11.96	53.0	5.4	118.2	**22.1**	**49.3**	
12.21	53.1			**22.1**		
15.88	52.7			**22.0**		
16.25	50.1			**20.9**		
16.88	51.3			**21.4**		
17.21	51.2			**21.3**		
17.88	51.2			**21.3**		
18.15	50.9			**21.2**		
19.00	51.7			**21.5**		
19.21	51.4			**21.4**		
19.22	51.8			**21.6**		
21.88	51.3			**21.4**		
22.25	50.8	1.6	119.8	**21.2**	**49.9**	
22.88	51.3			**21.4**		
23.22	51.3			**21.4**		
24.88	51.1			**21.3**		
25.22	50.9			**21.2**		
26.88	51.2			**21.3**		
27.21	50.9			**21.2**		
27.98	51.4			**21.4**		
28.21	51.6			**21.5**		
28.22	51.4			**21.4**		
30.88	51.6			**21.5**		
31.00	51.2	0.4	120.2	**21.3**	**50.1**	Stop Test

Loss of Envelope Material - The geotextile only allowed a total loss of 50 grams of sand envelope per linear foot during the 31 day test duration, with no indications of clogging (Note: clogging would have been indicated by declining flow rates with time). Most of the envelope loss occurred during sluicing and test start-up (days 1 through 4), with little loss during the test. The gradation of the wash-out material is shown in table 2. Since the AOS (Apparent Opening Size) of the geotextile is # 30 sieve, the vast majority (99.8 percent) of the wash-out material is smaller than #30 sieve.

Table 2 - Gradation of washout material

Test	Sieve Analysis (% retained on)				Weight (grams)	Flow rate (gpm/ft)	Duration
	# 8	# 30	# 100	# 200			
Sluicing	0	1	36	63	21.3	0.0	
Day 1	0	0	64	36	31.6	7.5	1 day
Day 2	0	0	73	27	17.0	8.1	1 day
Day 3	0	0	75	25	30.7	18.7	1 day
Days 4-5	0	0	71	29	12.2	23.5	2 days
Day 6-12	0	2	72	26	5.4	22.0	7 days
Day 13-22	0	0	63	37	1.6	21.2	10 days
Day 23-31	0	0	75	25	0.4	21.3	9 days
Totals					120.2		31 days

Piping of Base Soil - At the end of the test, 20 pounds of #200 silty fines were slowly added to the sump to determine if fines from the native soil could travel through the sand envelope, and whether these fines could then clog the geotextile. The sump pumps transported the fines into the PVC well-screen network. Some of the fines passed thru the slotted well screen, and were trapped in the first couple of inches of sand envelope surrounding the well screen. The majority of the fines were trapped in the bottom of the PVC well screen. No fine particles were detected in the outflow sieves, or found in the area of the geotextile when the completed test was carefully exhumed.

Discussion of Test Results

Table 3 summarizes the results from all three Pipe Box tests. The first two tests demonstrate the classic trade-off between flow rate and envelope retention (clogging and loss of envelope). To maximize flow rate (minimize clogging), large openings are required. Conversely to maximize envelope retention (minimize envelope loss), small openings are required. The third test shows that by the addition of the geotextile sock, we are able to optimize performance by simultaneously increasing flow rate and decreasing loss of the sand envelope.

Table 3 - Summary of results from all three tests

Test Configuration	Flow Rate (gpm / lin ft)	Sand Envelope Loss (grams / lin ft)	Test Duration and Comments
1/8-inch slots	1.74 Not Stable	200 Stable	8 Days - Not Stable
1/4-inch holes	6.3 Not Stable	850 Not Stable	24 Days - Not Stable
Geotextile Sock	21.3 Stable	50 Stable	31 Days - Stable
Improvements with Geotextile (factor)	3 to 12	4 to 17	

This optimized performance is achieved in three ways.

1. Improved retention of the sand envelope is achieved by the small openings in the geotextile (AOS = #30).

2. The improved flow rate is achieved by the creation of a void between the geotextile and the pipe perforation (figure 11). This void increases the effective open area from 2.1 in^2 per linear foot (perforation open area) to about 300 in^2 per linear foot (about half the surface area of the pipe).

3. Clogging is avoided because the sand envelope is stable and compatible with the knitted geotextile. (Note that the increased open area also decreases the flow velocities at the geotextile/sand interface, which decreases the chance of particle movement and clogging).

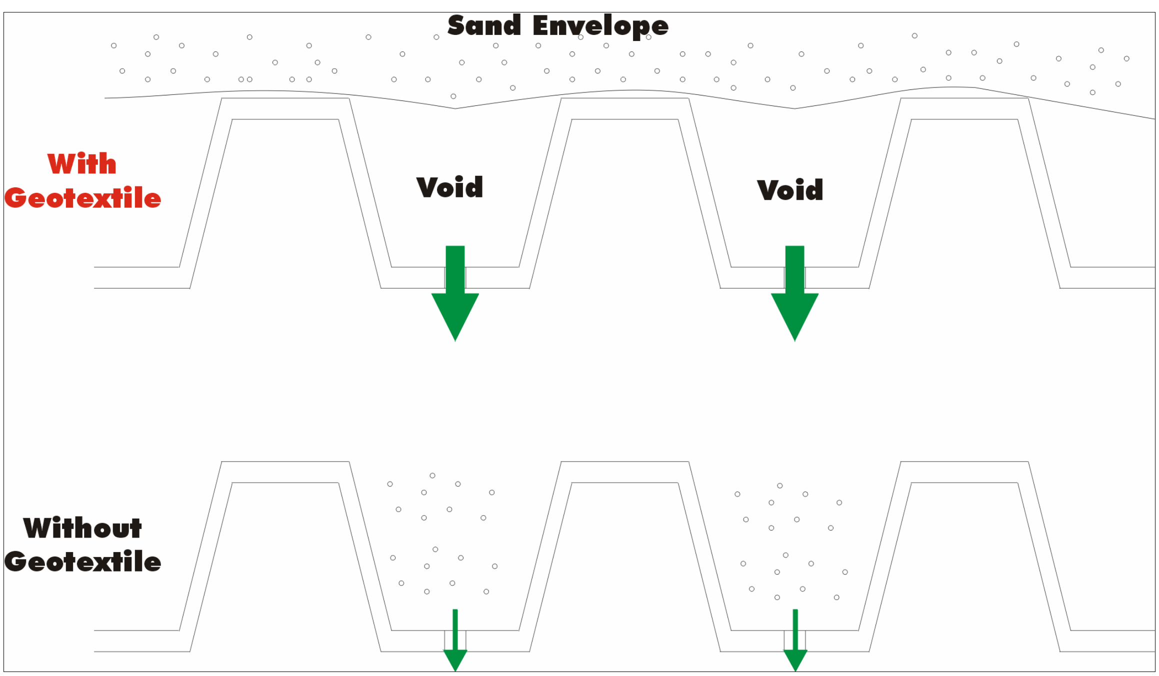

Figure 11 – Interaction between sand envelope and pipe perforations with and without geotextile.

Conclusions

1. Use of the geotextile sock in conjunction with the sand envelope optimized performance of the toe drain. Compared to previous tests without the geotextile, the flow rate increased by a factor of 3 to 12, while loss of the sand envelope decreased by a factor of 4 to 17.

2. Use of a geotextile sock in conjunction with a sand envelope is recommended for all future toe drain installations in areas with fine native soils. Use of the geotextile sock will improve toe drain performance by increasing flow rates and decreasing loss of envelope material. Experience gained with the use of geotextiles in toe drains will also improve Reclamation's ability to use geotextiles in other applications.

3. A traditional 2-stage filter (consisting of a gravel filter surrounded by a sand filter) is sometimes used in areas with fine native soils. However, traditional 2-stage filters are difficult and expensive to construct. Use of a geotextile as one stage of the 2-stage filter solves the constructability problem.

4. In the past, Reclamation has been reluctant to use geotextiles in our drains because of the potential for clogging when the geotextile was in direct with the native soils. In this test, the flow rate was stable over the 31-day test, showing no indication of clogging of the geotextile when used with a sand envelope .

5. Prior to this study, Reclamation would never use of a geotextile sock directly around the drain pipe. The standard practice was to install the geotextile along the perimeter of the excavated trench prior to backfilling with envelope material. The rationale was to locate the geotextile as far from the pipe as practical to increase surface area, decrease velocities, and minimize the chance of clogging. This testing has shown that sand envelopes are quite stable and do not cause clogging of a knitted geotextile sock. Various envelope configurations (both with and without geotextile) are discussed further in Appendix D.

6. Pipe Open Area - The drain pipe used for this test with the geotextile sock had only half the perforation open area of the two previous tests. However, the geotextile greatly increased the effective open area by maintaining a void between the geotextile and the pipe wall. Therefore, the perforation open area is less critical when using a geotextile sock.

7. Perforation Size - When using a geotextile sock, the size of the pipe perforations becomes irrelevant, since the geotextile acts as the filter for the envelope material.

Future Studies - The poor performance of the sand envelope at Lake Alice Dam was not anticipated. The dramatic improvement in performance with the addition of the geotextile sock was equally surprising. These results raise questions about whether similar improvements would be seen by using a geotextile sock with a traditional gravel envelope. Additional testing is required to evaluate the performance of a gravel envelope both with and without a geotextile sock.

References

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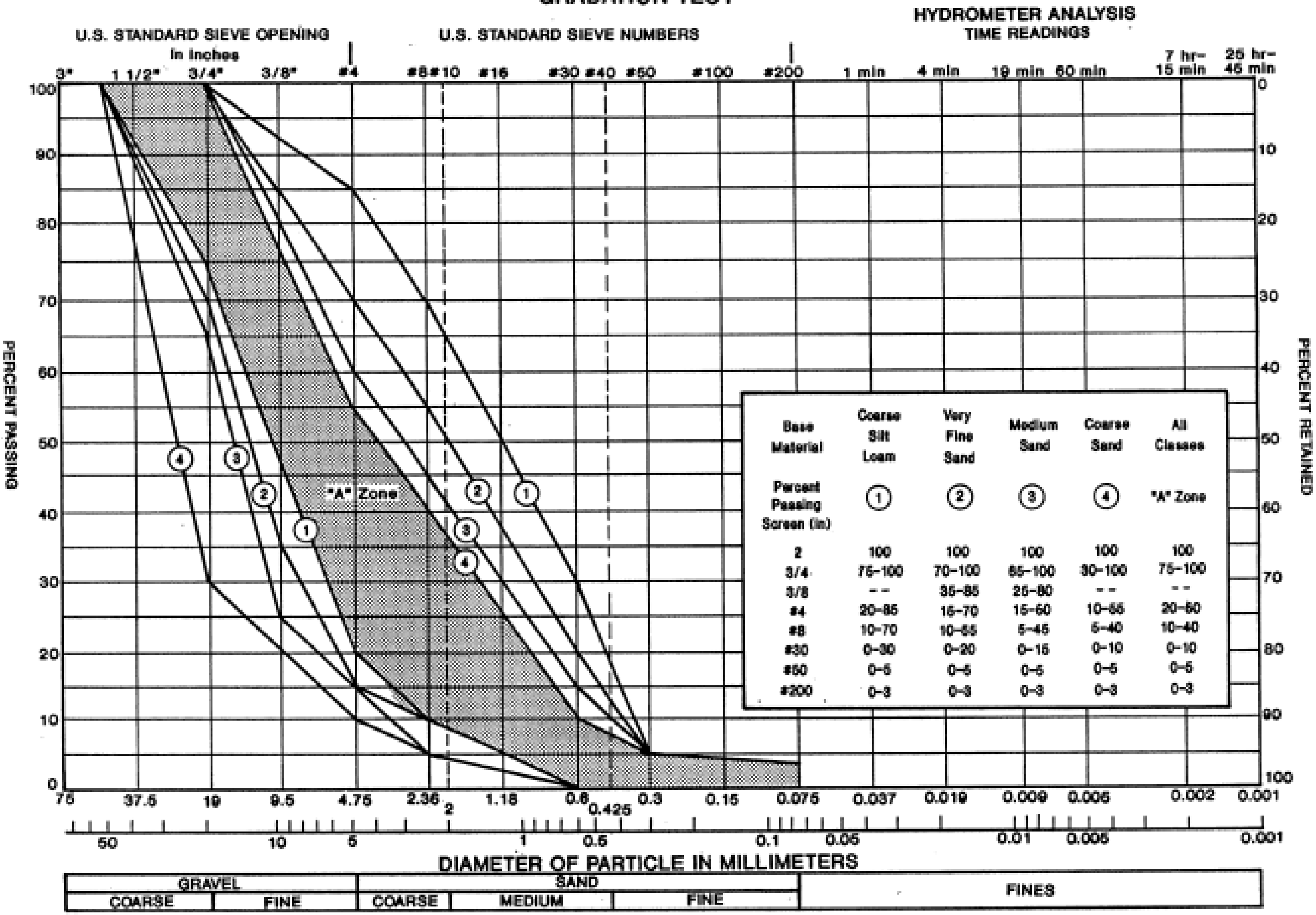
APPENDIX A

Bureau of Reclamation
Gradation Limits for Gravel Envelopes

GRADATION TEST



Base Material Percent Passing Screen (in)	Coarse Silt Loam (1)	Very Fine Sand (2)	Medium Sand (3)	Coarse Sand (4)	All Classes "A" Zone
2	100	100	100	100	100
3/4	75–100	70–100	85–100	30–100	75–100
3/8	– –	35–85	25–80	– –	– –
#4	20–85	15–70	15–60	10–55	20–60
#8	10–70	10–55	5–45	5–40	10–40
#30	0–30	0–20	0–15	0–10	0–10
#50	0–5	0–5	0–5	0–5	0–5
#200	0–3	0–3	0–3	0–3	0–3

APPENDIX B

Criteria for Sizing Perforations in Drain Pipe
(from Vlotman)

Table 28 Summary of Bridging Criteria

Bridging Criteria	Converted to O_{90}/d_{90} or D_{90}/d_{90} **	Remarks
Willardson (1979) $O_p/d < 3$ $O_p/d = 4$ $O_p/d > 5$	$D_{90}/d_{90} < 3$	Dry soil poured onto plate with perforations always bridged. usually bridged. never bridged.
Pakistan (Vlotman et al. 1992) $O_p/d_{15} = 1.7$ $O_p/d_{50} = 0.95$ $O_p/d_{85} = 0.67$	$D_{90}/d_{90} < 0.6$	Fine non-cohesive sand with $C_u = 3.3$ Bridging ratios for same soil. Ratio of d_{85} / d_{50} for the investigated soil was 1.5
US Army COE (1978) $O_p/d_{50} < 1$ $O_p/d_{50} < 0.83$	$D_{90}/d_{90} < 0.5$	For circular holes for slotted holes (originally: $D_{50}/O > 1.2$)
Schwab et al. 1986 $O_p/d_{60} = 1.5 - 3$ $O_p/d_{60} < 2$ $O_p/d_{60} = 4.9 - 9.9$ $O_p/d_{60} < 4$	$O_{90}/d_{90} < 1$ $D_{90}/d_{90} < 2$	Wet sand in parameter. Uniformly holed synthetic fabrics => $O_p = O_{90}$. Recommended for commercial fabrics. For pin holes as used in tests. Recommended for commercial perforation sizes.
Graauw et al. 1983 $D_{50}/d_{50} < 3$ $D_{50}/d_{50} < 5$	$D_{90}/d_{90} < 1.5$ $D_{90}/d_{90} < 2.5$	Granular filters. Cyclic flow. Stationary flow conditions.
Davies et al. 1978 $O_{50}/d_{50} < 5$	$D_{90}/d_{90} < 2.5$	Pipe field drains. O_{50} reported but probably is O_p.
John and Watson (1994) $O_{90}/d_{90} < 2 - 4$	$O_{90}/d_{90} < 2 - 4$	Physical model study: fabrics were not used but the authors converted their data already to O_{90}. (See text).

** - using Schwab's observations for conversions that the bridging factor with D_{60} are 13 - 83% higher than with D_{85}; where applicable 50% was used for the conversion. Also when fabrics were involved O_{90}/d_{90} is given, when granular material was used D_{90}/d_{90} was used.

APPENDIX C

Manufacturers Data Sheet
Geotextile Sock

Carriff Corporation's Drain-Sleeve Specifications

Description	2" Regular	3" Regular & Highway	4" Regular	4" Highway	5" Regular	5" Highway	6' Regular	6" Highway	6" Super Highway	6" Regular	10" Regular	12" Regular	15" Regular	15" Regular	24" Regular
Color Stripe	white	white	white	blue	orange	yellow	white	red	black	white	black	blue	orange	white	red
Oz/yd^2 relaxed	3.20	5.40	3.80	5.40	4.30	5.40	3.30	4.10	4.60	3.50	3.50	3.50	3.50	3.50	3.50
Oz/yd^2 Applied	2.10	3.50	2.50	3.50	2.80	3.50	2.80	3.50	3.90	3.00	3.00	3.00	3.00	3.00	3.00
Layflat Width															
Inches	5.25	5.50	6.75	6.00	7.00	7.00	10.00	9.75	10.50	14.00	14.00	16.00	25.00	27.50	30.00
mm	133	140	170	152	178	178	255	248	268	355	355	406	635	699	762
Cross Stretch															
inches	7.5	10	16	14.5	17.5	16.75	20.5	19	19.5	25	30	35	40	42	52
mm	190	254	406	368	445	425	520	483	498	635	762	890	1020	1065	1320
Applied Weight per 1000'															
lbs	11.0	23.0	25.0	30.0	30.0	36.0	35.0	44.0	53.0	52.0	65.0	81.0	103.0	115.0	150.0
kg	5.0	10.5	12.0	13.5	13.5	16.3	16.0	20.0	24.0	23.6	30.0	37.0	42.0	52.0	68.0
ft/#	90.0	43.0	40.0	33.0	33.0	27.0	28.0	22.0	19.0	19.0	15.0	12.0	9.0	8.0	6.0

** These weights may vary by application procedure and O.D. of pipe.*

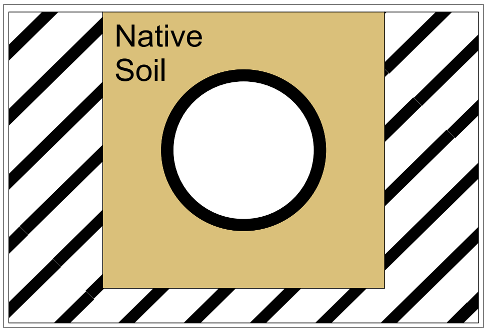
Specification	Test Method	Regular Sleeve
Fiber		Polyester
Weight (Oz/yd^2) Applied	ASTM D-3776	2.5 - 3.5
Thickness, in (mm)		0.040 (1)
Mullen Burst, p.s.i. (Kpa)	ASTM D-3786	100
Puncture Strength	ASTM D-4833	N/A
Air Permeability ft^3/ft^2/min (cm^3/cm^2/sec)	ASTM D-737	700 (335)
Water Flow Rate (US) gal/ft^2/min-3^o Head		700
Water Permeability by Permittivity s(-1)	ASTM D-4491	2.4
AOS, US sieve	ASTM D-4751	30
AOS, (UM)	ASTM D-4751	600
UV Degradation	ASTM D-4355	70%

Specifications are based on independent laboratory studies and are considered to be true and accurate.

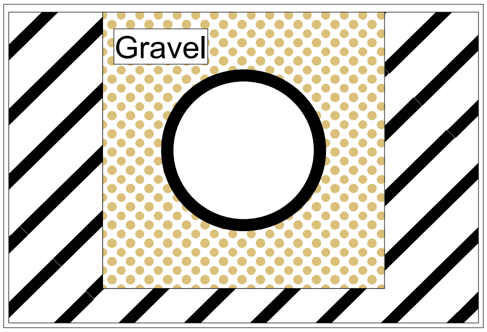
APPENDIX D

Discussion of Various Envelope Configurations

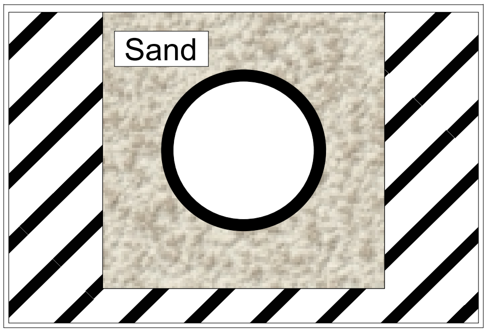
Appendix D - Configuration of Drain Envelopes



Case 1 - Drain Pipe backfilled with Native Soil. Easiest configuration to construct; however, high probability that the native soil will wash into the pipe through the perforations (piping) or plug the perforations (clogging) or BOTH. Not Recommended.

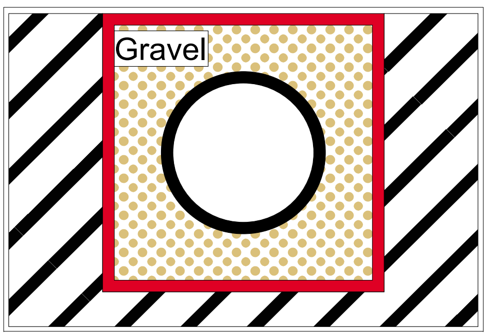


Case 2 - Drain Pipe with Gravel Envelope. Reclamation's typical design - Gravel should be graded to act as a natural soil filter for the native soil. Some piping of fines into the gravel envelope can be tolerated. However, these laboratory tests have raised questions about the interaction between the gravel envelope and the perforations.

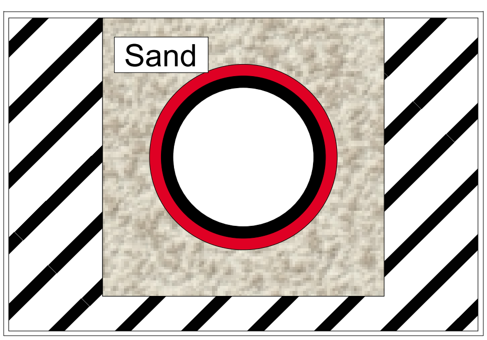


Case 3 - Drain Pipe with Sand Envelope. This design (used at Lake Alice Dam) works well to retain the fine native soils; however, laboratory tests have shown some loss of the sand envelope, and extensive clogging of the perforations with sand particles. These unexpected results show that Reclamation's pipe perforation criteria (Perforation Size $< \frac{1}{2}D_{85}$) addresses retention, but not clogging.

Case 4 - Drain Pipe with Geotextile Sock and Native Soil backfill. Contractors favor this method for ease of construction. However, high probability that the native soil will plug the perforations (clogging). Can sometimes work with a sandy native soil (see Case 6). Not Recommended!



Case 5 - Drain Pipe with Gravel Envelope and Geotextile Separator. Traditional method for employing a geotextile into a drain design. Geotextile should be properly designed to filter the Native Soil. Moving the geotextile away from the pipe significantly reduces the chance that the native soil will clog the geotextile, because of lower velocities and the larger geotextile area. Still questions about the Gravel/perforation interaction.



Case 6 - Drain Pipe with Geotextile Sock and Sand Envelope. Laboratory tests have shown that the sand will not clog the geotextile. The Geotextile should be properly designed to filter the sand, while the sand envelope should be properly designed to filter the Native Soil. Tests have shown that this design can optimize performance in difficult conditions involving high flow requirements with fine native soils.