Performance of a Textile Filter, Polishing Sand Filter and Shallow Trench System for the Treatment of Domestic Wastewater at the Northeast Regional Correction Center

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I. Introduction

An estimated half million households in Minnesota are not connected to public sewer systems. Along with the growing use and expansion of lakeshore cabins and resorts, many have the potential to degrade surface and groundwater resources as they depend primarily on individual sewage treatment systems (ISTSs) for the treatment and dispersal of domestic wastewater. Unfortunately, many are in noncompliance with state standards or are hydraulically failing to the surface. Effective treatment options are needed for the thousands of locations with restrictive soil and site conditions. Many of these sites occur along lakes and streams, creating a potential health hazard to swimmers and others using surface water for drinking water and recreation, leading to increased algal blooms, aesthetic nuisances and degraded fish habitat.

Packed bed textile filters, coupled with a site-specific soil dispersal system, were one of several options evaluated in Minnesota. Other systems tested in northeast Minnesota have included sand filters (single pass and recirculating), peat filters (in-ground and module), subsurface flow constructed wetlands, aerobic treatment unit, standard trenches, gravel filter and drip distribution (McCarthy et al., 1997, 1998, 1999, 2001; Anderson and Gustafson, 1998; Henneck et al., 1999, 2001; Axler et al., 1999, 2000; Monson Geerts et al., 2000, 2001; Pundsack et al., 2001; Christopherson et al., 2001). This paper provides an overview of the operation and performance of a recirculating packed bed textile filter, polishing sand filter and shallow gravelless trenches at the northern Minnesota research facility.

II. System Design and Construction

An Orenco Systems Incorporated (OSI) Reactex™ model RX-30 recirculating textile filter (OSI, 1999), polishing sand filter and shallow trenches were installed at the Northeast Regional Correction Center (NERCC) in July 1999. A representative from OSI was present on site to assist and oversee the day long construction (Figures 1 and 2). The dimensions of the Reactex™ unit are 4 ft. wide by 8.25 ft. long and a total depth of 32 inches, with a filter box area of ~33 ft^2. The Reactex™ unit is designed to treat between 450 and 600 gal/day of typical residential strength septic tank effluent (STE), with a biochemical oxygen demand (BOD_5) of 130 mg/L, total suspended solids (TSS) of 40 mg/L, total nitrogen (TN) of 65 mg/L and Oil and Grease (O&G) of 20 mg/L. The Reactex™ filter (hereafter referred to as textile filter), polishing sand filter and shallow trenches were initially set at an inflow of 250 gal/day, but after 15 months, were increased to a flow of 430 gal/day.

The system was retrofitted into the existing infrastructure of the research site, constructed on the crest of the lower hill between the Bord Na Móna Puraflo® systems and the conventional gravel trenches (Figure 3). A 1500 gallon two-compartment septic tank was dedicated to the system, and set up for recirculation of the Reactex™ filtrate (Figure 4). STE was timed dosed from the research site's head tank to the 1000 gallon side of the two-compartment tank. A 6-inch hole was cut in the center wall of the tank to maintain an even liquid level between the two compartments. Effluent was dosed to the textile module from a screened pump vault in the 500-gallon compartment. A small weep hole in the pump line allowed for drain-back to prevent freezing.

The textile module consists of a molded fiberglass shell with three removable fiberglass lids (Figure 5). The filter has three 8-inch compacted layers of textile media separated by two capillary breaks. The media consists of squares of non-woven polymer and synthetic fabric 3 in.(L) x 2 in.(W) x 0.25 in.(thick), with a porosity of ~80% and a surface area >5,000 ft^2/ft^3 (Bounds, 2001). A 1-inch diameter PVC pipe enters the module near the top of one end and attaches to a flexible 1-inch line connecting in the center of the distribution manifold at the opposite end of the filter. The distribution network is composed of four 1-inch evenly-spaced laterals, each with 8 orifices on12-inch centers, pointing upward and covered with orifice shields.

A ventilation fan assembly is located on the outside at one end of the textile filter, providing a continuous flow of air to the filter. Initially, the air intake piping was installed to use outside air, both winter and summer. But during the summer 2000, piping was added so warm air from a heated in-ground monitoring box could be used as a source of warmer air during winter months. Inside the assembly, a fan sensor signals an alarm if no air movement is detected.

A 3-inch diameter slotted, PVC under-drain pipe collects the effluent and returns it to the 1000 gallon compartment of the tank. Effluent samples were collected from the end of this pipe to determine performance of the textile filter. Thermocouples to measure temperature were placed inside the textile filter at two locations: 1) at the distribution network and 2) 12 inches below the network. Thermocouples were also installed in the dose tank and fan assembly.

The textile filter was initially set at an 8:1 recirculation ratio and dosed every 14.25 minutes for 45 seconds, resulting in 22.5 gal/dose. A solenoid valve, located between the textile filter and dose tank, was initially set to open every 3rd cycle to dose the polishing sand filter. When the solenoid opened, ~16.5 gallons of the 'mixed' (STE and textile filtrate) effluent from the pump vault were dosed to the textile filter, while ~9 gallons were dosed to the polishing sand filter. Initially, the controls were set to dose 250 gal/day to the polishing sand filter, which then drains by gravity to a pump basin for final subsurface dispersal.

In November 2000, the textile filter settings were changed to test the systems ability to treat about 450 gallons/day. The controls were reset to dose every14.08 minutes for 52 seconds, with the solenoid valve opening every 2nd cycle of operation.

The polishing sand filter was located in a second module next to the textile filter with the same dimensions (Figure 4). This type of sand filter is not part of the standard OSI package, and its primary purpose was for additional pathogen removal. At the bottom of the module, pea gravel was placed around the 3-inch slotted, under-drain pipe to minimize clogging. The module was filled with 18 inches of masonry sand (Table 1) having the following characteristics:

- D_{10}=0.17mm (10% sand media finer than 0.17 mm)
- D_{60}=0.68 mm (60% sand media finer than 0.68 mm)
- Uniformity coefficient (C_u)=D_{60}/D_{10}=4 mm
- 7% passing #100 sieve, ~2% passing the #200 sieve

The particle size distribution curve for the masonry sand (Figure 6) shows that this sand is finer than the sand typically used in single pass sand filters designed at loading rates between 1.0-1.25 gal/ft^2/day. Two inches of pea gravel was placed on top of the sand to support the distribution network and prevent scouring during dosing events. The pressure distribution network was nearly identical to the network installed in the textile filter. Thermocouples were placed at both the distribution network and 12 inches below it.

Effluent from the polishing sand filter drains by gravity through a 1.5-inch solid PVC pipe and into a 24-inch diameter pump basin containing a float tree assembly and 1/4-h.p. effluent pump. Effluent samples were collected from the discharge pipe in the sump basin to determine the combined performance of the polishing sand filter + textile filter. This effluent was pumped, on demand, to shallow trenches at ~25 gallons per dose.

The trenches consist of two 50-foot long laterals, 6-12 inches deep, connected by a common manifold with independent ball valves. The laterals were constructed using 1-inch PVC pipe with 5/32-inch orifices, two feet on center. Orifices were installed pointing up with orifice shields. After freezing problems the first winter, the laterals were rotated down to drain. The 1-inch laterals were covered with half-sections of 12-inch PVC pipe with inspection ports housed in valve boxes placed 25 feet apart. Thermocouples were installed to monitor temperature at two locations: 1) in the annular space above the pressurized lateral and 2) at the infiltrative surface next to the lateral.

III. Monitoring Methods

The textile system, like the other systems at NERCC, was monitored every three weeks. To determine treatment performance, samples were collected from the head tank (STE), from the textile filter where effluent returns to the recirculation tank, and from the sand filter where effluent entered the soil dispersal pump basin. The samples are analyzed for total suspended solids (TSS), biochemical oxygen demand (BOD_5), fecal coliform bacteria and total phosphorus (TP) (APHA, 1995) at the Western Lake Superior Sanitary District (WLSSD). All nitrogen species, including total-N (TN), ammonia-N (NH_4-N), and [nitrate+nitrite]-N (NO_3-N); pH and alkalinity were analyzed at NRRI (APHA, 1995; Ameel et al., 2000). Indigenous coliphage viruses (somatic and F-2 phages) were also determined at NRRI (Ameel, 2000) during part of the study.

Table 1. The particle size analysis of the polishing sand filter media commonly known as masonry sand. The sieve analysis was performed by OSI.

Sieve Analysis Report

OSI
Orenco Systems® Incorporated

814 AIRWAY AVENUE
SUTHERLIN, OREGON
97479-9012

TELEPHONE:
(541) 459-4449

FACSIMILE:
(541) 459-2884

Performed for: Eric Ball
Sample:
Date Received: 6/30/99
Date Tested: 6/30/99
Technician: K. Godard
Sample #: 63099ISF

Input

Weight of Evaporating Pan and Dried Sample (g) 1647.87
Weight of Evaporating Pan (g) 1059.85
Weight of Sample and Evaporating Pan After Washing (g) 1641.75

Sieve	Weight Before (g)	Weight After (g)
1/2	0.00	0.00
3/8	0.00	0.00
1/4	515.18	515.18
#4	512.86	512.86
#8	458.77	459.29
#10	480.27	484.20
#16	452.39	542.24
#30	396.77	560.96
#50	377.50	547.01
#100	365.90	486.53
#200	1232.69	1262.44
Pan	300.05	303.55

Results

Weight of Sample (g): 588.02
Percent Finer Than #200 Lost by Washing: 1%
D10 (mm): 0.17
D60 (mm): 0.68
Cu: 3.92

Sieve	Nominal Size (mm)	Mass Retained (g)	Retained	Passing
1/2	12.70	0.00	0.00%	100.00%
3/8	9.53	0.00	0.00%	100.00%
1/4	6.35	0.00	0.00%	100.00%
#4	4.75	0.00	0.00%	100.00%
#8	2.36	0.52	0.09%	99.91%
#10	2.00	3.93	0.67%	99.24%
#16	1.18	89.85	15.28%	83.96%
#30	0.60	164.19	27.92%	56.04%
#50	0.30	169.51	28.83%	27.21%
#100	0.15	120.63	20.51%	6.70%
#200	0.075	29.75	5.06%	1.64%
pan	-	9.62	1.64%	-

Temperature, conductivity and dissolved oxygen were measured in the field using a YSI85 multi-sensor meter. Temperatures were determined in both the textile and sand filter, in the recirculation tank, at the ventilation fan assembly and in shallow trenches. The inflow water meter, event counter, time-run counters and polishing sand filter water meter were recorded to determine flows. The depth of effluent ponding in trenches was measured during the study.

IV. Performance Results

The average influent wastewater strengths at NERCC were typical of STE: TSS 39-46 mg/L, BOD_5 194-241 mg/L, TP 13 mg/L and TN 60-72 mg/L. Crites and Tchobanoglaus (1998) identify typical STE as TSS 40-140 mg/L, BOD_5 150-250 mg/L, TP 12-20 mg/L and TN 50-90 mg/L. The operational and treatment performance of individual system components is presented in the following sections of this report.

1. Reactex™ Textile Filter

The textile filter was loaded at 196 gal/day during the first winter (1999-2000) and at 205 gal/day during two summers (1999 and 2000). During a third period of testing (November 2000-April 2001), the inflow was increased to 423 gal/day. The flow data excludes some times when the system was not operational, especially during the first winter of operation, when only a few sampling events occurred due to freezing in a drain line.

In the fall 1999, the force main from NERCC to the wastewater research site was shut-down for ~3 weeks due to internal problems unrelated to the textile system, and so flow was interrupted to the textile filter during this time. In early December 1999, the solenoid valve, which opens and closes via an electrical signal and allows effluent to flow to the polishing sand filter, failed. The system was shut down again for several weeks until the solenoid was replaced. Later in December 1999, the gravity discharge line from the polishing sand filter to the trench pump basin froze. The intake air assembly for the textile filter was drawing in cold outside air and temperatures dropped to near freezing in the filters. Evidently, the slow trickle of sand filter effluent, that drained through the 1.5-inch pipe, coupled with a lack of grass and snow cover and cold air temperatures (-15°F), contributed to freezing the line. The entire system was covered with hay in December 1999, and in January 2000, the pipe was thawed using a pressure jetting service. The pipe drained for a few days, but froze a second time, and the entire system was shut down until the pipe thawed in the spring. In May 2000, the discharge pipe was excavated and insulated with 2-inch polystyrene and wrapped with heat tape. Additional piping was installed so that warm air from the heated in-ground monitoring box could be used as a source of warmer air for the fan assembly. During the second winter of operation, there were no freezing problems associated with the textile system.

Despite the initial difficulties, performance of the textile filter was excellent in removing solids, organic matter and pathogens (Table 2). Effluent TSS was <6 mg/L (88-94% removal) and BOD_5 was < 6 mg/L (98% removal) during both winter and summer. Fecal coliform bacteria removal was also excellent, with fecals at 357-775 cfu/100mL (>99.7% removal) winter and summer, respectively, just exceeding the body contact standard of 200 cfu/100 mL.

Phosphorus removal by the textile filter was low, as expected, with <1% TP removed summer (12 mg/L TP) and ~20% TP (11 mg/L TP) removed the first winter. Nitrogen removal was also low (14-21% TN removal) during the initial 15-month period, with effluent levels of 64 mg TN/L in winter and 59 mg TN/L in summer. Ammonium-nitrogen was low (<6 mg N/L), both winter and summer, with >90% converted to other nitrogen forms, largely nitrate-nitrogen at 50-61 mgNO_3-N/L in effluent. The highly-nitrified effluent indicates the system was operating under favorable conditions for this biological conversion: adequate supply of oxygen (though the fan assembly), alkalinity (via STE) and warm temperatures. The textile effluent had ~3 mg/L DO in summer and ~7 mg/L DO in winter. Inflow temperatures were relatively warm year-round, 9.6°C (winter) and 16.5°C (summer), while textile effluent temperatures were slightly cooler than winter inflows (8.0°C) but warmer than summer inflows (16.8°C).

Table 2. Performance of Orenco Systems Inc. Reactex™ RX30 textile filter at NERCC, August 1999 through November 2000 at a flow of ~200 gal/day.

Recirculating Textile Filter (August 1999 - November 2000)						
Parameter	WINTER (Nov. - Apr.)			SUMMER (May - Oct.)		
	INFLOW[1]	Effluent[2]	% - Removal[3]	INFLOW[1]	Effluent[2]	% - Removal[3]
Q (gal/d)	196			205		
TSS (mg/L)	43 (15)	2.5	94	48 (23)	5.8	88
BOD_5 (mg/L)	247 (74)	5.4	98	171 (67)	3.2	98
TP (mg/L)	14 (2.0)	11	21	12 (1.9)	12	0.6
TN (mg/L)	81 (24)	64	21	69 (11)	59	14
NH_4-N (mg/L)	75 (21)	5.9	92	63 (13)	1.7	98
NO_3-N (mg/L)	0.00 (0.00)	50	(nitrification)	0.01 (0.00)	61	(nitrification)
fecal coliforms[4]	$8.3x10^5$	357	99.9	$2.8x10^5$	775	99.7
Temp. (°C)	9.6 (3.5)	8.0	na	16.5 (3.3)	16.8	na
DO (mg/L)	0.26 (0.25)	6.6	na	0.18 (0.10)	2.9	na
EC25 (umhos)	920 (454)	812	12	1050 (124)	752	28
Alkalinity (mg/L)				452	34	92

Total number of sampling events = 4 winter, 10 summer, between August 1999 and November 2000;
[1]average STE during the seasonal period (± Standard Deviation); except alkalinity, n=1.
[2]average seasonal values;
[3]Percent removal based on Effluent: ((inflow-outflow)/inflow) x 100 = % removed;
[4]the geometric mean colony-forming units (cfu) per 100ml.

The inflow to the textile system was increased from 205 to 423 gal/day in November 2000 for about 6 months. Although the flow more than doubled, treatment efficiency remained nearly the same (Table 3). At the higher flow, TSS was <2 mg/L (95% removal) and BOD_5 was <5 mg/L (98% removal). Fecal coliform bacteria increased slightly from 775 to1597 cfu/100mL, but the removal rate was still high (99.4%). Phosphorus removal remained low (15% TP removal), but nitrogen removal improved somewhat (32% TN removal). Most of the remaining nitrogen, not lost to the atmosphere or biologically assimilated, was converted to nitrate-nitrogen (36 mg N/L), while ammonium-N was low (~2mgN/L) and DO was high (5 mg/L). Incoming STE was 6.8°C, while the textile effluent cooled slightly (5.8°C). The air intake for the fan assembly had been routed into the heated, in-ground monitoring box to supply warm air to the textile filter during this winter, similar to it being located in the basement of a house.

Table 3. Performance of Orenco Systems Inc. Reactex™ RX30textile filter system at NERCC, November 2000 through April 2001 at a flow of 423 gal/day.

Recirculating Textile Filter (November 2000 - April 2001)			
Parameter	WINTER (Nov. - Apr.)		
	INFLOW[1]	Effluent[2]	% - Removal[3]
Q (L/d)	423		
TSS (mg/L)	39 (7.2)	1.9	95
BOD_5 (mg/L)	241 (45)	4.4	98
TP (mg/L)	13 (2.8)	11	15
TN (mg/L)	60 (6.8)	41	32
NH_4-N (mg/L)	60 (2.2)	2.2	96
NO_3-N (mg/L)	0.03 (0.02)	36	(nitrification)
fecal coliforms[4]	3.1×10^5	1597	99.4
Temp. (°C)	6.8 (1.7)	5.8	na
EC25 (umhos)	999 (150)	627	37
DO (mg/L)	0.43 (0.24)	5.0	na
Alkalinity (mg/L)	376	89	76

Total number of sampling events = 6 winter, between November 2000 and April 2001;
[1]average STE during the seasonal period (± Standard Deviation); except alkalinity n=1.
[2]average seasonal values;
[3]Percent removal based on Effluent: ((inflow-outflow)/inflow) x 100 = % removed;
[4]the geometric mean colony-forming units (cfu) per 100ml.

Overall, the textile filter consistently performed at a high and consistent level in removing solids, organic matter and pathogens. The textile filter performed equally well at both loading rates evaluated in the study, and its performance was consistent with OSI product literature for TSS and BOD_5. The textile unit itself did not experience major operational problems, although the fan blower assembly had a minor electrical problem that was easily corrected in April 2001.

2. Polishing Sand Filter + Textile Filter

As previously described, the polishing sand filter was dosed at 196 gal/day (first winter) and at 205 gal/day (two summers) using 'mixed' effluent at a loading rate ~6 gal/ft^2/day. Since the polishing sand filter was dosed with recirculated effluent + incoming STE, the data actually reflects the combined performance of the textile and sand filter (Table 4).

Table 4. Combined performance of the polishing sand filter + Reactex™ textile filter at NERCC, August 1999 through November 2000 at a flow ~200 gal/day. The polishing sand filter was loaded at ~6 gal/ft^2/day during this period.

Polishing Sand Filter + Textile Filter (August 1999 - November 2000)						
Parameter	WINTER (Nov. - Apr.)			SUMMER (May - Oct.)		
	INFLOW[1]	Effluent[2]	% - Removal[3]	INFLOW[1]	Effluent[2]	% - Removal[3]
Q (L/d)	196			205		
TSS (mg/L)	43 (15)	1.9	96	48 (23)	1.1	98
BOD_5 (mg/L)	247 (74)	3.7	99	171 (67)	1.5	99
TP (mg/L)	14 (2.0)	9.3	34	12 (1.9)	9.5	21
TN (mg/L)	81 (24)	52	36	69 (11)	63	9
NH_4-N (mg/L)	75 (21)	0	100	63 (13)	0	100
NO_3-N (mg/L)	0.00 (0.00)	49	(nitrification)	0.01 (0.00)	61	(nitrification)
fecal coliforms[4]	$8.3x10^5$	8	99.99	$2.8x10^5$	28	99.99
Temp. (°C)	9.6 (3.5)	9.3	na	16.5 (3.3)	16.7	na
DO (mg/L)	0.26 (0.25)	6.0	na	0.18 (0.10)	4.6	na
EC25 (umhos)	920 (454)	646	30	1050 (124)	753	28

Total number of sampling events = 4 winter, 10 summer, between August 1999 and November 2000;
[1]average STE during the seasonal period (± Standard Deviation);
[2]average seasonal values;
[3]Percent removal based on Effluent: ((inflow-outflow)/inflow) x 100 = % removed;
[4]the geometric mean colony-forming units (cfu) per 100ml.

The textile +sand filter were very effective at reducing solids to <2 mg TSS/L (96-98% removal), organic matter to <4 mg BOD_5/L (99% removal) and fecal coliform bacteria to <10 cfu/100 mL (winter) and <30 cfu/100 mL (summer). After passing through the polishing sand filter, the effluent was completely nitrified using 'mixed' effluent (ammonium-N was undetectable at <0.1mgN/L). The sand filter provided additional phosphorus removal (13-20% TP removal), which will probably decrease with continued use.

Like the textile filter, flow to the polishing sand filter was increased to 423 gal/day in November 2000 to January 2001, which is a loading rate of ~13 gal/ft^2/day. During this time, treatment performance remained essentially unchanged, with TSS <1 mg/L and BOD_5 2 mg/L (Table 5). Fecal coliform bacteria remained low, but increased slightly to 142 cfu/100 mL (99.99% removal). Phosphorus removal remained low, but nitrogen removal improved substantially to

47% TN removal (32 mg/L TN).

In January 2001, the polishing sand filter failed hydraulically when several inches of ponding was observed in the module. The masonry sand was removed and replaced with gravel so the textile filter could continue to be operated and monitored. A number of factors are suspected for causing the hydraulic failure, most notably the high loading (~13 gal/ft²/day) and increased frequency of dosing using 'mixed' effluent. A slime layer (Biomat) was observed at the sand surface, which reduced the infiltration rate into the sand. Fines in the sand (7% fines <0.15 mm) may have contributed to this problem, although the high loading using 'mixed' effluent is the primary suspect. The improved nitrogen removal at the higher flow may have been associated with ponding in the sand filter as well. After the sand filter ponded, its performance was not monitored.

Table 5. Combined performance of the polishing sand filter + Reactex™ textile filter at NERCC, November 2000 through February 2001 at a flow 423 gal/day. The polishing sand filter was loaded at ~13 gal/ft²/day during this period.

Polishing Sand Filter + Textile Filter (November 2000 - February 2001)			
Parameter	WINTER (Nov. - Feb.)		
	INFLOW[1]	Effluent[2]	% - Removal[3]
Q (L/d)	423		
TSS (mg/L)	39 (7.2)	0.6	98
BOD_5 (mg/L)	241 (45)	2.0	99
TP (mg/L)	13 (2.8)	10	23
TN (mg/L)	60 (6.8)	32	47
NH_4-N (mg/L)	60 (2.2)	1.1	98
NO_3-N (mg/L)	0.03 (0.02)	32	(nitrification)
fecal coliforms[4]	$3.1x10^5$	142	99.95
Temp. (°C)	6.8 (1.7)	4.8	na
DO (mg/L)	0.43 (0.24)	4.4	na
EC25 (umhos)	999 (150)	563	44

Total number of sampling events = 3 winter, between November 2000 and February 2001;
[1]average STE during the seasonal period (± Standard Deviation);
[2]average seasonal values;
[3]Percent removal based on Effluent: ((inflow-outflow)/inflow) x 100 = % removed;
[4]the geometric mean colony-forming units (cfu) per 100ml.

3. Coliphage monitoring

The monitoring of pathogens at NERCC included indigenous coliphages (somatic and F-2 phages), commonly found in the human 'gut' and, thus, in wastewater. Coliphages are viruses (bacteriophages) that infect and replicate in the bacterium *Escherichia coli (E. coli).* Somatic coliphages specifically infect *E. coli* by attaching themselves to the cell wall, while F-2 coliphages are male-specific phages that infect only the "male" strains of *E. coli*.

The unique feature about coliphages is that they are similar in size and shape to human enteric viruses, such as poliovirus and hepatitis A. Although the bacterial group 'fecal coliform bacteria' are routinely used as indicators of fecal contamination, coliphages may be better indicators of viral contamination because of their similar size, shape and resistance to disinfection (Gerba, 1987).

Coliphages were present in the facility's STE at levels between 200 and 9720 pfu/mL coliphages during nearly two years of monitoring, from July 1999 to May 2001 (Table 6). During startup (period 1), the textile filter provided reasonably good removal of coliphages (~97%), ranging

Table 6. Combined performance of the textile filter and polishing sand filter at NERCC in removing coliphages (and fecal coliform bacteria) at flows ~200 gal/day (July 1999-Oct 2000) and 423 gal/day (Nov 2000-May 2001).

Parameter	**Period 1 (Start-up+ Fall)** July 1999-Nov 1999 Flow ~ 200 gal/day			**Period 2 (Full Summer)** June 2000-Oct 2000 Flow ~200gal/day			**Period 3 (Full winter)** Nov 2000-May 2001 Flow ~ 423 gal/day		
	Inflow	Textile effluent	Sand [2] filter effluent	Inflow	Textile effluent	Sand [2] filter effluent	Inflow	Textile filter	Sand [1] filter effluent
Median coliphage (pfu/mL)	3875	214	2	1300	12	0	587	44	4
Mean coliphage (pfu/mL) [2] (% removal)[3]	3004	88 97.1	1 99.9	896	10 98.9	1 99.9	741	34 95.4	4 99.5
Number of coliphage samples	5	4	6	6	6	5	9	9	4
Minimum coliphage (pfu/mL)	690	13	0	200	0	0	210	5	3
Maximum coliphage (pfu/mL)	9720	634	24	2750	33	3	9930	59	6
Mean fecal coliform bacteria (cfu/100mL)[2] (% removal)[3]	$8.3x10^5$	357 99.9	8 99.9	$2.8x10^5$	775 99.7	28 99.9	$3.1x10^5$	1597 99.4	142 99.9

[1] Sand filter effluent coliphage data is for the period Nov 2000-Jan 2001 (Period 3) due to hydraulic overload in January 2001. Hydraulic loading to sand filter was ~6 gal/ft^2/day (Period 1 and 2) and ~13 gal/ft^2/day (Period 3).
[2] Geometric mean.
[3] Percent removal based on Effluent: ((inflow mean-outflow mean/inflow mean) X 100 = % removed.

from 13 to 634 pfu/mL and a mean of 88 pfu/mL. The polishing sand filter provided near complete removal (99.9%) of coliphages with 1 pfu/mL, comparable to the removal rate for fecal coliform bacteria (99.9%). Even at the high loading rate of 6 gal/ft^2/day, 18 inches of masonry sand provided excellent disinfection. We would expect that a native soil, classified as a medium to fine sand, would provide a similar level of treatment.

The median and mean effluent coliphage levels are comparable, except during startup (period 1) when coliphages were more variable. It probably took a few months for the biological community to become established within the textile media, which was visibly noticeable by a change in color from white to orange-brown. The performance of the textile filter in removing coliphages improved by the summer (period 2) to10 pfu/mL (98.9% removal). The coliphages in textile effluent were also less variable during the summer (0 to 34 pfu/mL) as compared to startup (13 to 634 pfu/mL). At both loading rates, the polishing sand filter provided a very high level of coliphage removal (99.9%), with means of 1 pfu/mL at ~6 gal/ft^2/day and 4 pfu/mL at ~13 gal/ft^2/day. The removal of fecal coliform bacteria followed the same trend as the that of the coliphages at both loading rates.

Despite a doubling of the inflow during the second winter (period 3), coliphage removal remained high (95.4% removal) with only a slight decrease in performance (24 pfu/mL). This same trend was observed in the removal of fecal coliform bacteria at the higher flow. Up until the time the sand filter ponded in January 2001, the polishing sand filter consistently removed coliphages to <6 pfu/mL.

4. Shallow Trenches

The following section describes the overall performance of shallow trenches, dosed with high-quality, nitrified effluent over two years. This evaluation was limited to the ability of a shallow trench system, at high loading rates, to operate effectively year-round. An obvious drawback of this type of trench configuration is its shallow placement, limited soil cover and potential for freezing.

A. Temperature Monitoring

Temperature in the trenches ranged from a high of ~20°C during the summer to a low of -5°C during the winter (Figure 7). During the first winter (1999-2000), the laterals froze in December 1999 at about the same time the following incidents occurred: 1) the solenoid valve malfunctioned and had to be replaced, 2) the filters were near freezing due to the fan intake drawing in cold outside air, and 3) the sand filter discharge pipe froze. Temperature of the sand filter effluent was also near freezing at this time.

The winter of 1999-2000 was unusual because of the lack of snow cover throughout most of the winter. The average annual snowfall, based on 50-years of data from the National Weather Service, is ~80 inches, with an average of 13 inches of snow on the ground (Figure 8). Although we received ~60 inches of snow, there was only 1 to 6 inches of snow on the ground at NERCC for a few weeks that winter (Figure 7). The freezing problem was likely the result of several factors, including: 1) turned-up orifices that prevented the laterals from draining, 2) near-freezing effluent temperatures, 3) lack of snow cover and cold air temperatures, 4) and insufficient (too slow) drain back from the manifold to the pump basin. In a regional freeze survey conducted in NE Minnesota that winter, more than 440 onsite systems had some type of freezing problem, and the lack of snow cover was reported as the leading cause of frozen systems (Reed et al., 2001). The survey respondents indicated that the most common location of freezing was in sewer piping and pump lines, just as we had experienced at NERCC.

In May 2000, the trench system was modified to ensure that the manifold would drain back to the pump basin, and it was insulated with 2-inch polystyrene. The laterals were rotated down to drain after each dose. During the second winter (2000-2001), the trench system operated successfully without any freezing problems. But snowfall and temperatures were near normal levels this winter and the ground was covered (insulated) with up to 2 ft of snow (Figure 7). Although temperatures at the infiltrative surface and air gap were near freezing, the laterals did not freeze and the soil continued to accept the highly treated wastewater throughout the winter. It is impossible to know if our modifications would have prevented the previous winter's freezing problems.

B. Soil Hydraulic Loading Rates

Hydraulic loading rates to the soil, and depth of ponding in trenches, are presented in Figure 9. During the period July1999-October 2000, one trench (50 ft^2) was dosed with highly treated, nitrified effluent, at an average loading rate of 4.7gal/ft^2/day. Minimal ponding was observed, except for a brief time in September 1999 when 6-inches of ponding occurred due to surface water running off the site and through the trench area. After this event, a swale was constructed to divert surface water away from the area. The trenches were not used from December 1999 to March 2000 (the sand filter discharge pipe had froze), but they were used from April 2000 to October 2000 at a hydraulic loading rate of 4.7gal/ft^2/day without any problems.

In November 2000, the flow to the textile filter was increased to 430 gal/day and both trenches were loaded at 4.5 gal/ft^2/day (Figure 9). In January 2001, flows were temporarily reduced for a short time due to ponding in the sand filter, and again, in May 2001 due to an electrical problem in the fan blower motor.

Some sporadic ponding of effluent was observed in the trenches. In November 2000, ~0.5 inch ponding occurred, following a high flow event associated with changing the flow to the textile filter, resulting in a loading rate of ~7 gal/ft^2/day. About 1-inch of ponding occurred in March 2001during spring snow melt (Figure 9) when ~2 ft of snow melted within a few weeks. And in May 2001, ~2 inches of ponding occurred. This temporary ponding occurred during a very wet period (8 inches above normal precipitation) and after an unusually high flow event, which resulted in a loading rate of ~8 gal/ft^2/day. The soil was able to "temporarily" accept the highly treated wastewater, despite the above-normal precipitation.

The sandy loam soil, at this location, successfully dispersed the highly treated effluent for two years from the textile filter system. The average soil loading rate was 4.6 $gal/ft^2/day$, but varied sporadically up to 8 $gal/ft^2/day$. We would not suggest that a typical home dispersal system be loaded at these high rates. Rather, multiple trenches should be installed (relatively inexpensive) with the capability of using some trenches while 'resting' other trenches by using simple ball valves. This simple technique of managing the system would be expected to extend the life of the trench system.

V. Summary and Conclusions

The NERCC research site provided an excellent location to evaluate the treatment and operational performance of a proprietary recirculating textile filter (OSI Reactex™ textile filter, model RX-30), coupled with a polishing sand filter (for enhanced pathogen removal) and shallow infiltration trenches for final treatment and dispersal. Our third party testing provides the industry, homeowners and regulators with an unbiased evaluation of the treatment and operational performance of the system.

The overall treatment and operational performance of the system was excellent throughout the study. At the hydraulic loading rates tested (~200 and 430 gal/day), the textile filter effectively removed solids (TSS <6 mg/L), organic matter (BOD_5 <6 mg/L), fecal coliform bacteria (357-1597 cfu/100mL) and coliphages (10-88 cfu/mL) from residential strength septic tank effluent. The Reactex™ textile filter removed little phosphorus (<15% TP), presumably due to microbial immobilization and particulate removal since the textile media is inert and does not have an inherent ability to remove phosphorus. Nitrogen removal was limited, but TN removal improved over time, ranging from 21% during the first winter of operation (n=4 events) to 32% during the second winter (n=6). The long-term ability of this type of recirculating textile filter to remove high levels (>60% TN when recirculated back to a dose tank) of nitrogen in a cold climate, like northern Minnesota, is unknown. The system provided nearly complete nitrification and levels of ammonium-N were nearly always <6 mg N/L and typically ~2 mg N/L, even in winter at higher flows.

A number of modifications were made to the system during the time frame it was operated and monitored. Table 7 lists those events and steps taken to remedy or prevent problems. We recommend that the air intake for the fan blower assembly be located in the owner's house (basement) or other warm location. The system froze at NERCC during the first winter due, in part, to cold air brought into the Reactex™ system through the blower assembly. As a precautionary measure, the fiberglass shell and cover should also be insulated. The control panel operated without any major problems, except for some loose wiring in the blower fan assembly, which tripped the control panel breaker. The solenoid valve had to be replaced, but this valve is not typically part of the standard OSI package.

The standard Reactex™ system typically includes a textile module, pump vault and pumps, controls and soil dispersal (i.e. trench) system. At NERCC, an experimental sand filter using 18 inches of mason sand was installed between the textile filter and soil dispersal trenches. At a loading rate of 6 gal/ft^2/day, the polishing sand filter provided the following: 1) reduced fecal coliform bacteria to <142 cfu/100mL and coliphages to <4 pfu/mL, 2) completely nitrified the effluent, and 3) removed additional phosphorus. But when the loading rate was doubled to ~13 gal/ft^2/day, the polishing sand filter failed hydraulically after just three months. A microbial slime was obvious at the sand infiltrative surface and fines in the mason sand may have contributed to the failure.

Table 7. Textile filter system time line of upgrade practices made from July 1999 to May 2001.

Date	Event
July 1999	Construction and installation of OSI Reactex™ model RX-30 textile filter at the NERCC Onsite Demonstration Site.
September 1999	Insulated the textile and polishing sand filter modules with 2-inch polystyrene, including covers, access lids, and the solenoid/water meter in-ground box. Diverted the drainage of surface water around the infiltration trenches using a swale.
December 1999	Replaced solenoid valve due to electrical problem.
December1999 - January 2000	Frost penetration and freezing in the gravity drain piping between the polishing sand filter and infiltration trenches pump basin. Line was pressure-jetted out, but re-froze soon thereafter. Experienced freezing of condensate in ventilation fan assembly and in infiltration trenches. Entire system turned off until May 2000.
May 2000	Insulated drain line between polishing sand filter and dispersal field pump basin, including electrical heat tape. Insulated and re-routed the air supply for the ventilation fan assembly to the heated solenoid/water in-ground box. Insulated the trench manifold and rotated trench laterals to point orifices down to allow for drainage of laterals after dosing.
November 2000	Increased flow and changed the dosing schedule to the textile filter and polishing sand filter (and trenches) based on an inflow of 430 gal/day.
January 2001	Ponding occurred in the polishing sand filter. Sand was removed and temporarily replaced with gravel. Continued to operate the system.
April-May 2001	Electrical problems with the fan blower. An electrical short repeatedly tripped the control panel breaker. Rewired the blower assembly to correct the problem.

The drain line from the sand filter froze the first winter due to minimal snow and grass cover and a slow drip of filter effluent though the small diameter (1.5 inch) pipe. Even though the discharge pipe from the polishing sand filter had a negative grade for drainage, the pipe froze. Although several hundred onsite systems had freezing problems in northern Minnesota the winter 1999-2000, we recommend that a 4-inch drain pipe be used and that hay or straw be used on the ground surface to protect the drain pipe from freezing the first winter of use.

The shallow soil absorption trenches, using pressurized 1-inch laterals, also froze during the first winter. Suspected reasons for freezing were a lack of snow cover, near freezing effluent (the sand filter discharge line froze), and orifices turned up so the pipe would not drain properly.

Modifications were made to the piping and no freezing occurred during the second winter of operation, although it is impossible to know if our modifications would have prevented the previous winter's freezing problems.

The sandy loam soil was able to hydraulically accept the highly-treated, nitrified effluent at a loading rate of ~4.6 gal/ft^2/day, expect during a brief period following construction when concentrated surface water filled up one trench. A swale was constructed that successfully diverted all surface water away from the soil dispersal system. Minimal ponding (1-2 inch) occurred during the two years of monitoring, and this ponding was generally associated with a high dosing event, spring snow melt or following high rainfall periods.

Packed bed textile filters are one of several types of onsite wastewater treatment system tested in Minnesota since 1995. Other systems have included single pass sand filters (McCarthy et al., 1997, 1998, 1999; Pundsack et al., 2001), recirculating sand filters (Christopherson et al., 2001), recirculating gravel filters (McCarthy et al., 1998), single pass in-ground and modular peat filters (McCarthy et al., 1997, 1998; Monson Geerts et al., 2000, 2001; Pundsack et al., 2001), subsurface flow constructed wetlands (Axler et al.,1999, 2000; Henneck et al., 1999, 2000; Pundsack et al., 2001), aerobic treatment units (McCarthy et al., 2001) and drip distribution. The web site http://www.bae.umn.edu/septic/LCMR provides a compilation of these and other publications from the project.

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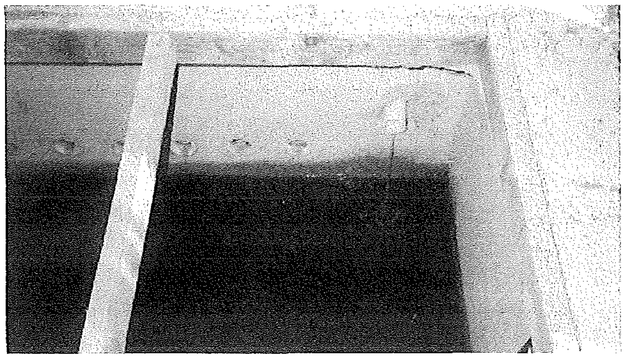
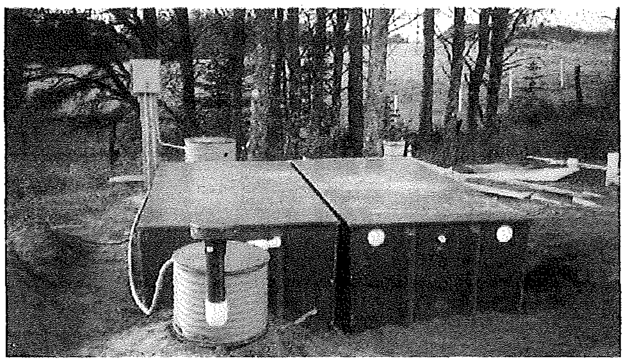
Figure 1. Reactex™ textile filter system installed at NERCC in 1999.

Reactex Demonstration System at the NERCC Research Facility

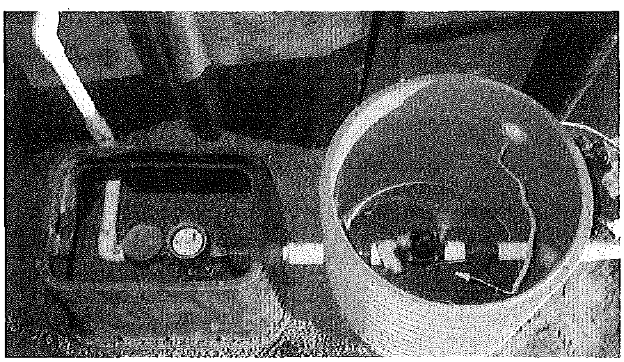


Inlet pipe into 1500 gallon two compartment tank. Effluent is metered in from central dosing tank. Incoming waste strength is relatively high, with approx. average strengths as follows:

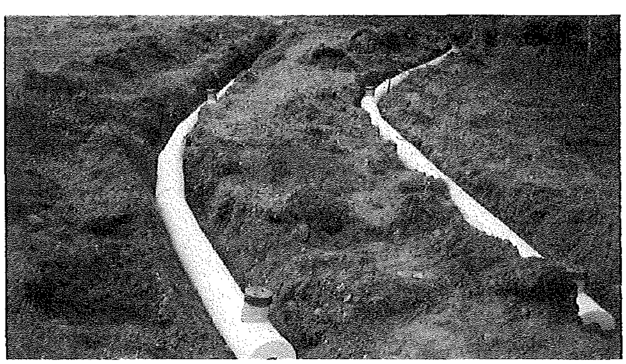
TSS:	46 mg/L
BOD:	241 mg/L
TN:	72 mg/L
TP:	13 mg/L



Reactex Textile Filter is on left. Polishing sand filter is on right. ventilation fan assembly is in foreground and provides continuous air flow to the Reactex Filter.

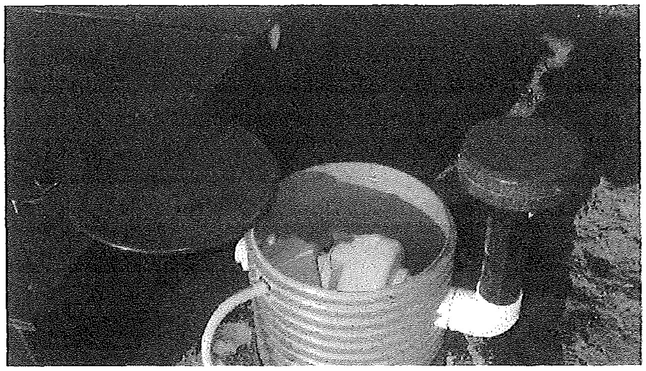


Solenoid valve in access riser on right opens every 3rd pump cycle (as long as middle float is in "up" position) to allow flow to the polishing sand filter. Water meter to left measures flow to the polishing sand filter and can be used to corroborate the metered daily flow from the central dosing tank.



Shallow gravel-less drainfield consists of two 50 foot long trenches (12 in. wide x 10 in deep) with 12 inch half pipe covering pressurized laterals. Pressurized laterals have 5/32 inch holes that are 2 feet on center.

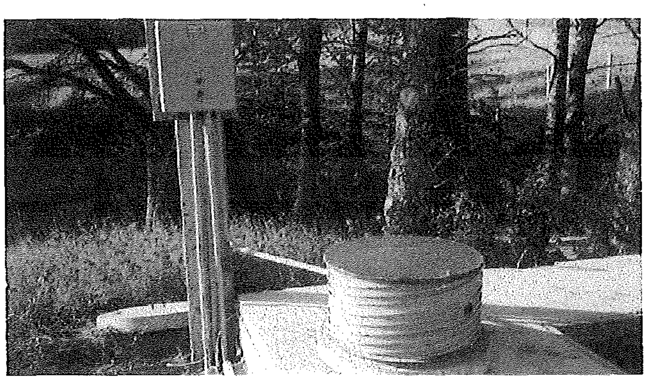
Figure 2. Reactex™ textile filter system installed at NERCC in 1999.



Inside of ventilation fan assembly. Splice box contains fan sensor that will signal an alarm if no air movement is detected.

Reactex Filter in right. Polishing sand filter on left. Solenoid valve and flow meter in foreground.

Inside view of filters with distribution manifolds sitting on top of textile and sand medias.



Biotube Pump Package is under tank riser. MVP Control Panel on post.

Figure 3. General layout of systems at NERCC.

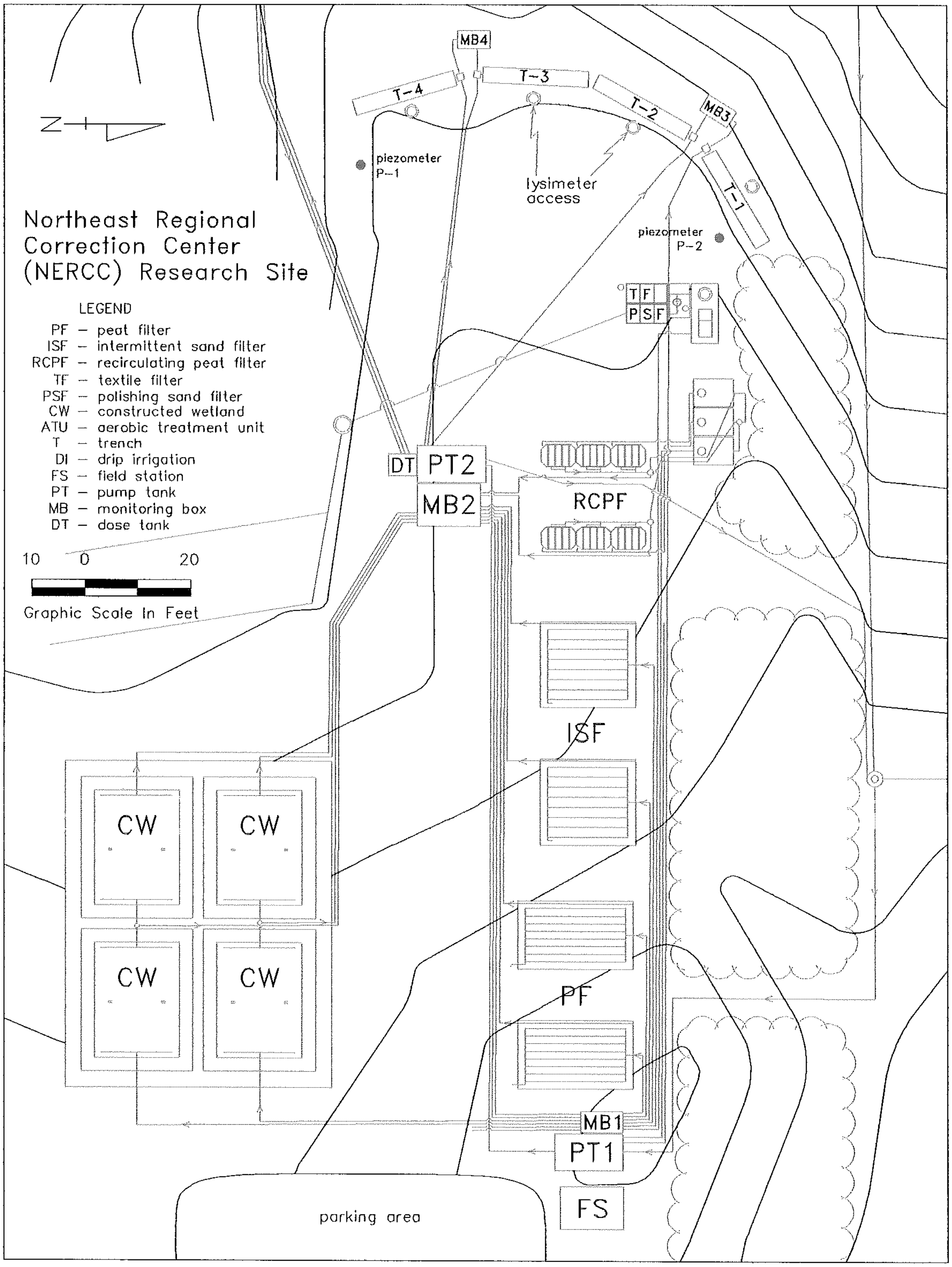


Figure 4. Layout of the textile filter system includes a two-compartment tank, Reactex™ textile filter, polishing sand filter, pump basin and infiltration trenches at NERCC.

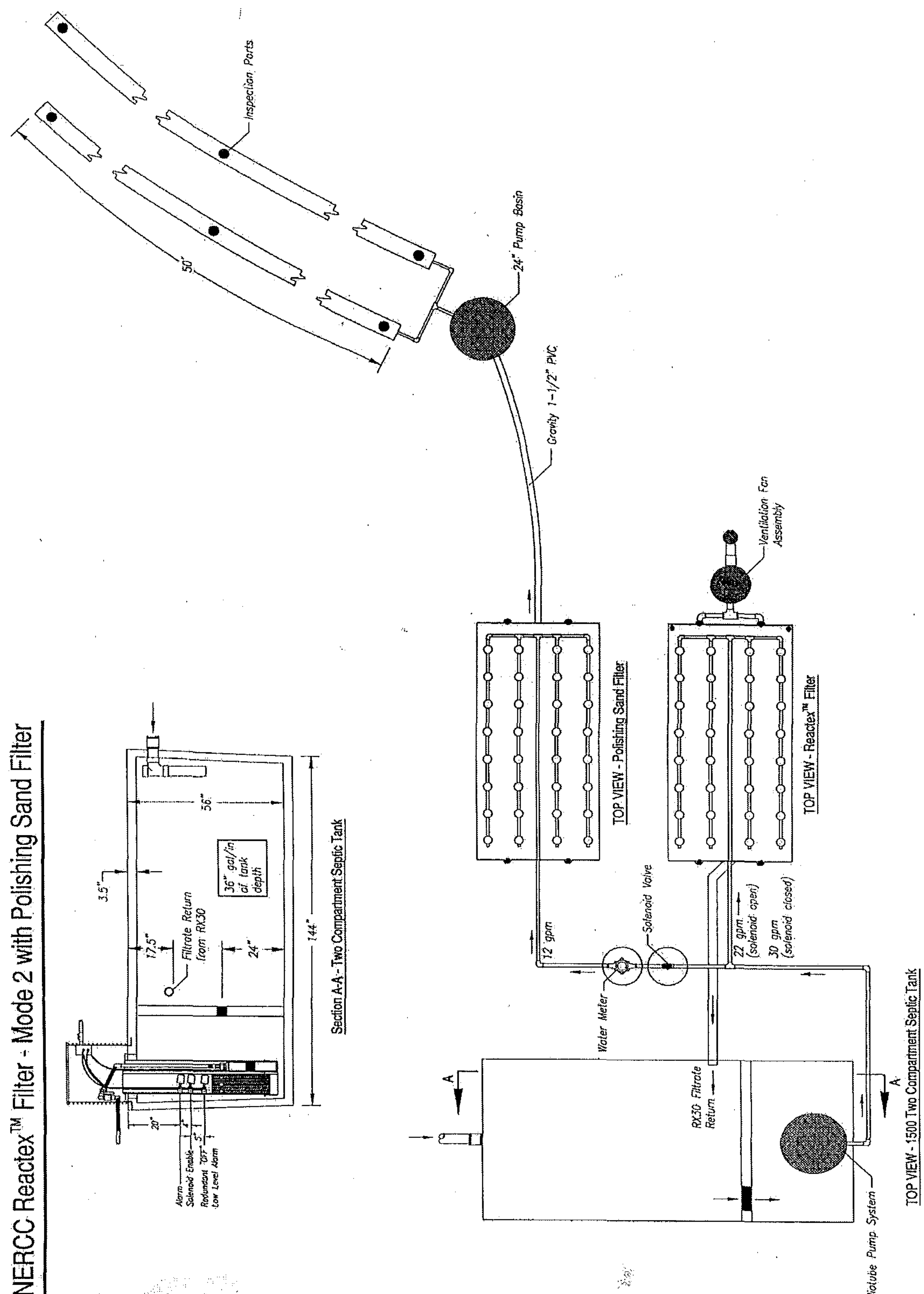
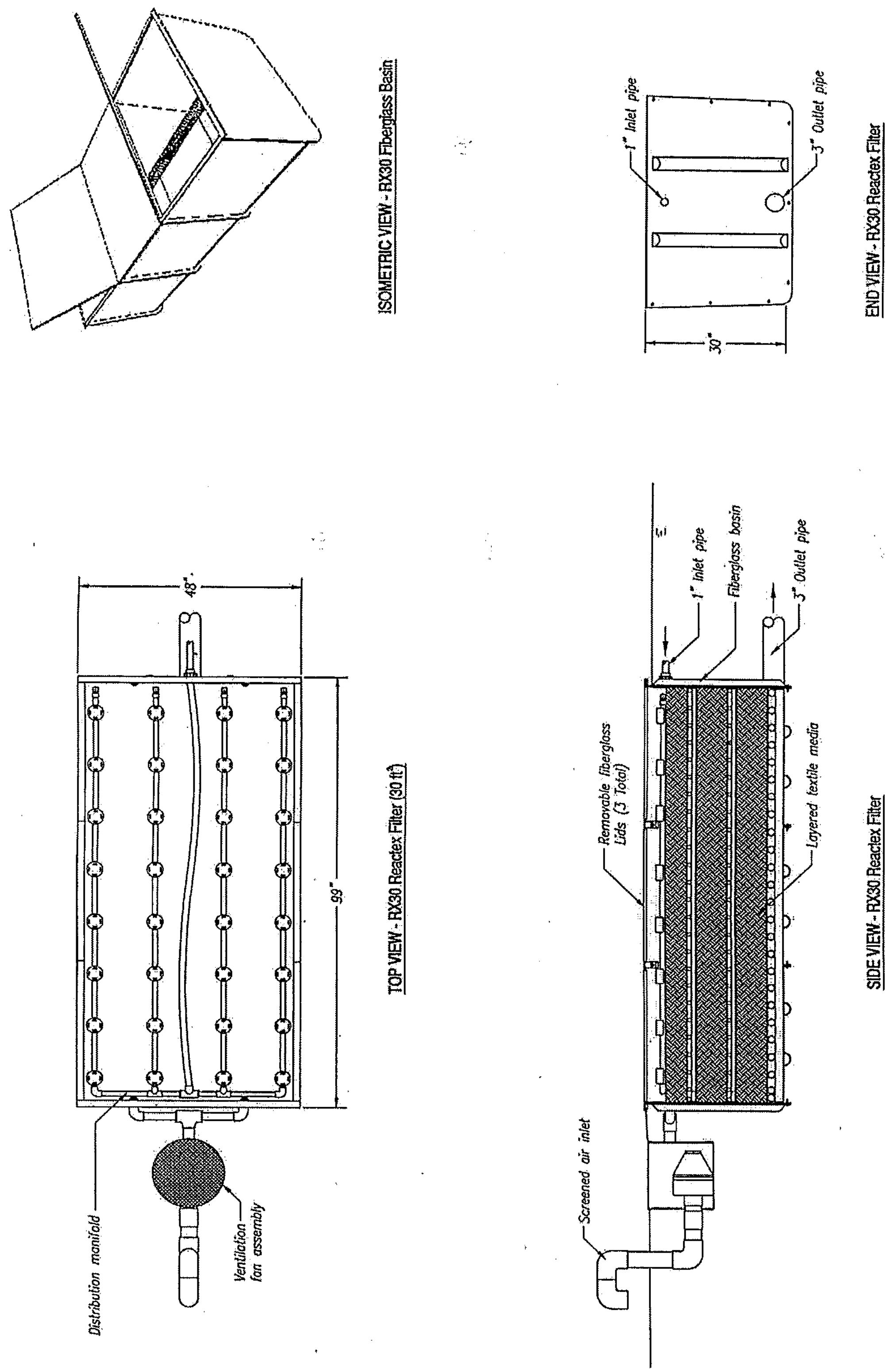


Figure 5. Views of the RX30 Reactex™ textile filter installed at NERCC.



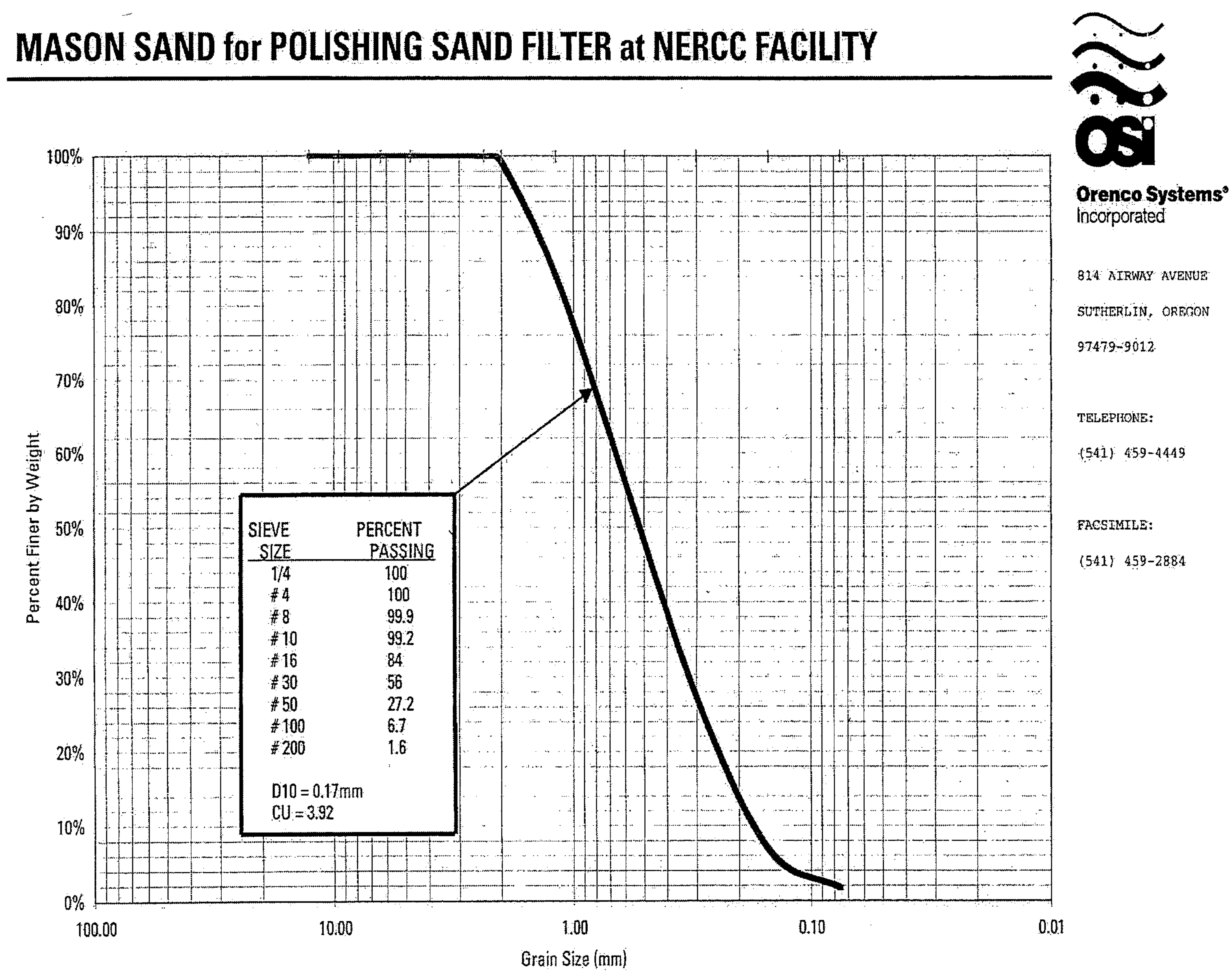


Figure 6. Particle size distribution of the masonry sand used in the polishing sand filter at NERCC, provided by Orenco Systems Inc.

Figure 7. Temperature and snow cover for the two shallow trenches loaded with highly treated textile/sand filter effluent, June 1999-May 2001.

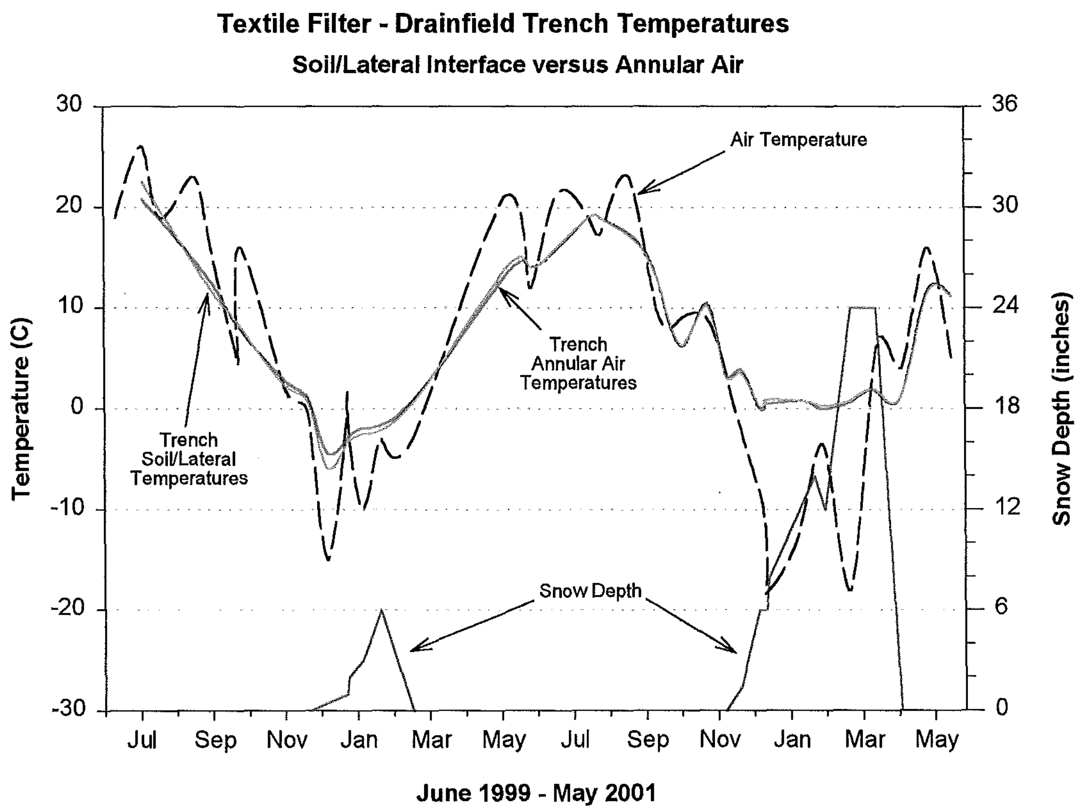


Figure 8. Total annual snowfall (inches) and snow depths (inches) measured on the ground and recorded by the National Weather Service at the Duluth International Airport for 50 years (1950-2000).

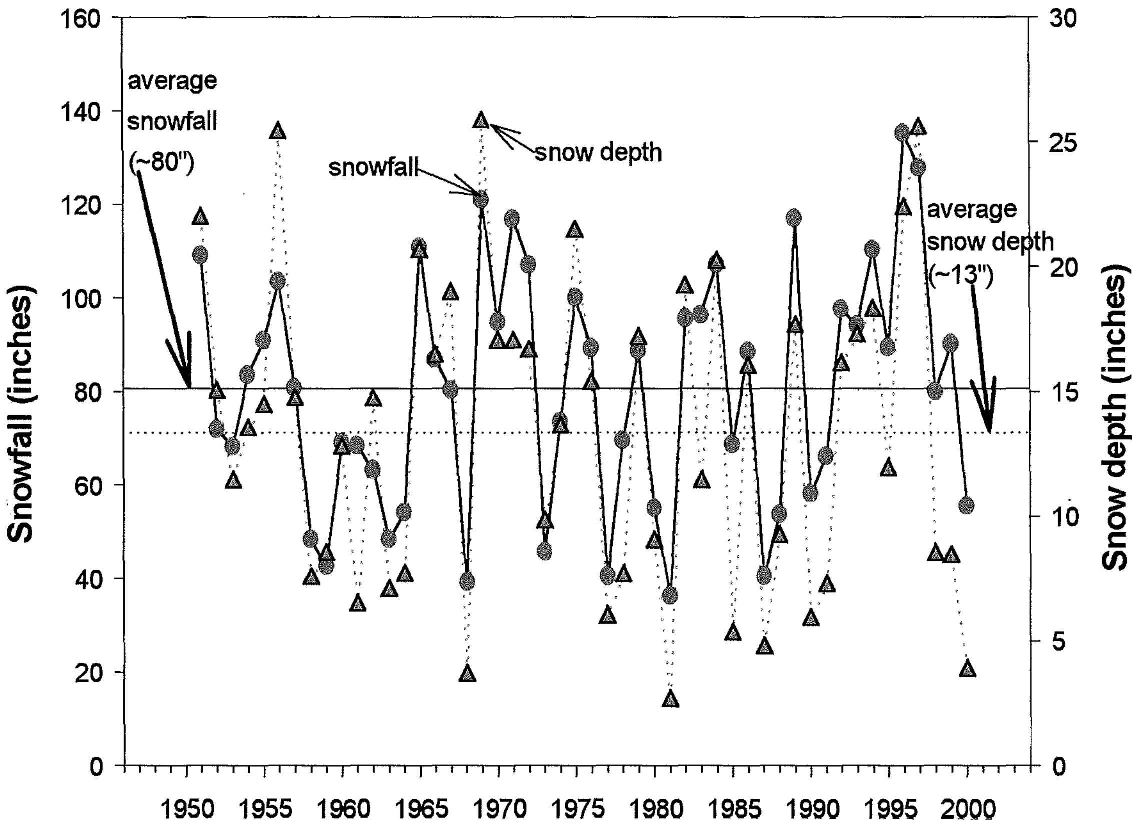


Figure 9. The hydraulic loading rates and ponding depths in two shallow trenches dosed with highly treated textile/polishing sand filter effluent, June 1999-July 2001.