NERCC* Individual Alternative Wastewater Treatment Systems: Pollutant Removal in 2003 and Long-term Performance

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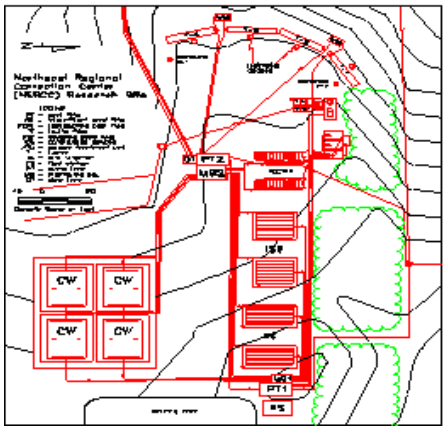

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NERCC Individual Alternative Wastewater Treatment Systems: Pollutant Removal in 2003 and Long-term Performance

Abstract

Near 500,000 Minnesota residences, commercial establishments and resorts rely on the use of onsite wastewater treatment systems to treat generated wastewater from these facilities. The need for effective onsite wastewater treatment systems in the state is growing to service new developments and to upgrade outdated on site sewage treatment systems (a.k.a. septic systems) with modern individual, shared, cluster or small community wastewater treatment systems. In 1995, a research site was established in northern Minnesota at the Northeast Regional Correction Center (NERCC) near Duluth, Minnesota, to design, construct, operate and monitor the performance of a variety of onsite wastewater treatment systems for use in the cold climate of Minnesota. The purpose of the research facility was to test the effectiveness of several onsite wastewater treatment technologies in removing organic matter, solids, pathogens, and nutrients at the same location using the same wastewater under identical climatic conditions. This phase of the study reports upon system performance during the 8th year of operating the facility (2003) after a 1 year monitoring hiatus due to a funding shortfall. Performance results were obtained throughout the year for: replicated, in-ground single pass peat filters, modular peat filters using both Irish and a Minnesota peat, replicated, in-ground single pass sand filters, replicated subsurface flow constructed wetlands, and a recirculating textile filter with shallow infiltration trenches. Results for 2003 were tabulated in comparison to results from previous years. In addition, all of the data for these systems from all years of operation is summarized and tabulated. Additional discussion regarding operation and maintenance issues is also included.

Keywords:
alternative technologies, performance-based systems, cold-climate, constructed wetlands, sand filters, peat filters, textile filters, pathogens, wastewater treatment, on-site septic systems, individual sewage treatment systems (ISTS)

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 homes, cabins and resorts, many have the potential to degrade surface and groundwater resources, as they depend primarily on individual sewage treatment systems (ISTS) for treatment and dispersal of domestic wastewater. Many onsite wastewater systems are not in compliance with the state's prescriptive code or are hydraulically failing to the surface. Effective treatment options are needed for the thousands of locations with restrictive soil and site conditions, where many of these conditions occur in sensitive lake and stream environments, 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.

The Northeast Regional Correction Center (NERCC) Septics Demonstration/Research Facility near Duluth, Minnesota began in October 1995. The facility was designed and operated by scientists at the Natural Resources Research Institute of the University of Minnesota-Duluth in collaboration with the St. Louis County Environmental Health Department and the Western Lake Superior Sanitary District (WLSSD). NERCC's main objective was to establish a research/demonstration facility for directly comparing the year-round performance, operation and maintenance of various alternative on-site treatment systems. Replication, a single source of septic tank effluent, and a common set of performance based design criteria for concentrations of total suspended solids (TSS), biochemical oxygen demand (BOD_5) and fecal coliforms were central to the project's goals. The first set of systems included single pass sand and peat filters, subsurface flow constructed wetlands (with a second cell to enhance nitrogen removal) and a conventional trench system. These systems were operated nearly continuously through 2001 after which the facility was closed due to a funding shortfall. The modular peat filters were added in 1998 and the textile filter was added in 1999.

After a hiatus in 2002, funding from the Lake Superior Coastal Program allowed a more limited monitoring effort to be conducted in 2003 which is reported here. Because of funding limitations, this report serves mostly as a data report with relatively little detailed analysis of the 2003 data. The focus of the study was to revive the monitoring program at NERCC for an additional year, to determine how well the major treatment systems would perform after a year with minimal wastewater inputs (essentially a "wet" hibernation), and how they would perform in relation to their previous history and during a winter that turned out to have much more snow than in recent years. However, this also provided the opportunity to combine the 2003 seasonal data with the historical data to report summary tables of seasonal performance for all years of operation.

More than 25 performance-based, or alternative on-site wastewater treatment systems have been evaluated for varying time periods at NERCC Demonstration/Research Facility or as part of a series of resort-based Iron Range Resources and Rehabilitation Agency (IRRRA) demonstration projects, since 1995. These include:

- in-ground, single-pass sand filters (McCarthy et al., 1997, 1998, 1999; Anderson et al., 1998; McCarthy and Monson-Geerts, 2003a);

- in-ground single-pass peat filters (McCarthy et al., 1997, 1998; Monson Geerts et al., 2000, 2001a, Anderson et al., 1998);

- pre-engineered modular peat filters using both Irish and Minnesota peat (Monson Geerts et al., 2001b);

- granular peat filters (McCarthy et al., 1997, 1998);

- subsurface flow constructed wetlands (Axler et al., 1999, 2000, 2001; Henneck et al., 1999, 2001; Kadlec et al. 2003; McCarthy et al., 2002);

- a textile filter coupled with polishing sand filter and shallow dispersal trenches (McCarthy et al., 2001a);

- a drip irrigation system that discharges to soil depths of 0.5, 1, 1.5 and 2 feet below ground (McCarthy et al. 1997; McCarthy and Monson Geerts 1998**;**

- an aerobic treatment unit coupled with drip distribution (McCarthy et al., 2001b);

- standard infiltrative trenches, a recirculating gravel filter and drip distribution (McCarthy et al., 1997, 1998; McCarthy and Monson Geerts 1998); and

- a recirculating sand filter with shallow infiltration trenches (McCarthy and Monson Geerts 2003b).

Additional detailed studies of the efficiency of pathogenic bacteria (*Salmonella)* and model virus (MS-2) removal were performed on the in-ground peat and sand filters and the constructed wetlands (Pundsack 2001; Pundsack et al. 2001, 2004; Olson 2004; Olson et al. 2004a,b). The University of Minnesota Extension Service's Onsite Wastewater Treatment web site ***http://septic.coafes.umn.edu/Research/index.html*** provides a compilation of these and other publications from the project and many of the technical reports are also downloadable. Additional on-site wastewater treatment related information relevant to the region can be found at the Duluthstreams.org website (***http://duluthstreams.org/stormwater/on_site.html***) and from St. Louis County at ***http://www.co.st-louis.mn.us/publichealth/Environmental/envir_pro_septic.htm*** .

II. General Operation and Performance Monitoring

Detailed descriptions of system designs, operating specifications, monitoring program designs and field and laboratory methodology are reported in the journal manuscripts and technical reports listed above. Briefly, septic tank effluent is pumped from a lift station, located near the NERCC main building complex, and into a 2,500 gallon concrete septic tank installed at the research site, where effluent is time-dosed to the treatment systems at the test site (Figure 1). Once the effluent has passed through the in-ground, single-pass sand and peat filters, the constructed wetlands and the modular peat filters, it flows by gravity to a lower monitoring box, where flows are measured using tipper-buckets and samples are collected. Effluent then drains either to conventional trenches with monitoring piezometers

located at 1, 2 and 3 feet below the trench or drains to an adjacent 2,000 gallon collection tank. From here, the effluent is pumped to the NERCC facility drainfield for final dispersal. Effluent from the modular textile filter flows by gravity to a small pump station and is dosed to a separate set of shallow trenches. Funding was only available to monitor inflow and outflow water chemistry for the treatment systems, and not the lysimeters placed under the research trench systems.

Figure 1 presents a plan view of the NERCC demonstration/research facility. Figures 2-6 show schematics of the individual systems and Figures 7 -11 are photographs of the various systems.

The NERCC systems were reactivated on November 19, 2002 and were sampled 10-16 times between January and December 2003 at approximately three week intervals. Septic tank effluent samples were collected using a peristaltic pump from the main head tank. Effluent samples from the constructed wetlands, sand filters, in-ground peat filters and modular peat filters were collected where they drain into tipper buckets located in the lower monitoring box. Textile filter effluent was sampled where it returns into the recirculation tank and the 'mixed effluent samples' were collected from the forcemain dosing the effluent to the textile filter.

Both peat filters were re-activated in November 2002 after a 1-year shut down. Before being re-activated, the modular peat filters were opened up and each module inspected. At that time, the Irish peat subsided about 10% by volume and was wet but not saturated. However, the Minnesota peat subsided significantly more than the Irish peat, losing ~30% of its original volume, exposing the distribution network in all 3 modules. Furthermore, the peat was saturated with water. A pick-up truckload (~4 yds) of coarse peat screenings was added to the modules containing Minnesota peat to once again fill each of the three modules. Additional maintenance information is available directly from the *Bord na Mona Puraflow* website at ***http://www.bnm.ie/environmental/small_scale_wastewater_treatment/puraflo.htm.***. Similarly one can find operation and maintenance information for the textile filter at ***http://www.orenco.com/ots/ots_index.asp.*** Inflow monitoring meters and screens were cleaned for all of the systems and wastewater was applied for about 2 months prior to beginning the monitoring program in order to reestablish their microbial communities.

All wastewater samples were analyzed for total suspended solids (TSS), biochemical oxygen demand (BOD_5), fecal coliform bacteria (fecal coliforms), and total phosphorus (TP) at the Western Lake Superior Sanitary District (WLSSD) Laboratory according to standard methods following APHA (1998). Nitrogen analyses (total-N [TN], ammonium-N and nitrate/nitrite-N) were analyzed by the NRRI Central Analytical Laboratory (methods following APHA, 1998 and Ameel et al. 1998). Both laboratories were certified by the Minnesota Department of Health.

In the field, temperature, specific electrical conductivity (EC25), and dissolved oxygen of the effluent were measured using a YSI 85 multi-sensor meter. Inflows were determined using individual water meters at the inflows for the sand filters, in-ground peat filters and constructed wetlands. Timers and event counters were used for the textile filter and modular peat filters. Outflows may be assumed to equal inflows for all systems except the

constructed wetlands (CWs) where evapotranspiration can reduce outflows to zero during warm summer days. Because we were not able to monitor the rates of outflow from the CWs, their reduction efficiencies were calculated by comparing effluent to influent concentrations instead of by mass reduction as was done for previous years and as is appropriate for CWs. This difference would be insignificant for most fall, winter and spring samplings but would likely tend to underestimate performance in the summer when nutrients and other water quality parameters may be in relatively high concentrations but only in a small trickle of effluent. Therefore, the CW performance data are conservative. Temperatures within each system were determined using an Omega hand-held digital thermometer. Climate data were taken from the National Weather Service site located at the Duluth International Airport, approximately 15 km south of NERCC.

III. Performance Results

This section summarizes effluent water quality data and removal efficiencies, and compares the operation and performance of the peat, modular peat, sand and textile filters and the constructed wetlands in 2003 in relation to historical data.

A. Septic tank influent

During the 2003 monitoring period, incoming septic tank effluent from the correctional facility was comparable to residential strength septic tank effluent although at the high end of the range for many constituents (Table 1). Typical residential strength effluent is reported to range from 50-100mgTSS/L (NERCC was a bit low and averaged 47 mg/L), 140-200 mgBOD_5/L (NERCC was relatively high strength and averaged 229 mg/L), 10^6-10^8 cfu/100mL fecal coliform bacteria (NERCC was lower at 10^4-10^5 cfu/100mL in 2003 and a long-term average of ~ 4x 10^5 cfu/100mL), 5-15 mgTP/L (NERCC averaged ~ 14 mgP/L), and 40-100 mgTN/L (NERCC averaged ~ 80-85 mgN/L; Crites and Tchobanoglaus, 1998; EPA, 2002). Effluent "strength" in 2003 was similar to that measured from 1996-2001 (see McCarthy et al. 2003, Axler et al. 2001, Monson-Geerts et al. 2001).

B. Treatment system effluents - 2003

Effluent quality data for 2003 for the 9 monitored systems are tabulated in Tables 2-10 and average annual removal rates for 2003 in Table 11. Tables 12-16 summarize seasonal effluent concentrations and removal efficiencies for all years of operation. The systems had been "rested" from November 2001 to November 2002 due to insufficient funding, but otherwise were used near continuously from 4 to 7 years, depending upon the year of construction or installation.

1. Sand filters:

During this 6th year of operation at ~195 gal/day (0.6 gal/ft^2/day), the replicated single-pass sand filters required only routine maintenance, limited to flushing the pressure distribution network which was done in October 2003. Overall, the sand filters provided the best performance in removing BOD (99%), TSS (96-99%), phosphorus (48-50%), and fecal coliform bacteria (>99.8%), followed closely by the modular peat filter containing standard Irish peat. The sand filters removed the most phosphorus, 48-50%, presumably due to the iron content of the media since it was removed from a minepit on the 'Iron Range' (a.k.a. "Iron Ridge") north of Virginia, MN. Other advanced treatment systems tested in 2003

removed relatively little phosphorus, 6-13%. Overall nitrogen removal was minimal (4%) by both sand filters but nitrification was nearly complete at >95% and ammonium levels averaged <3 mgN/L). This result is consistent with the relatively high dissolved oxygen levels in the sand filter effluents (annually means ~ 5 mgO_2/L). Both filters consistently exceeded secondary treatment standards for TSS and BOD_5, with TSS always < 6 mg/L (mean <2) and BOD_5 always <7 mg/L (mean ~ 2 mg/L) with no seasonal difference in removal rates. Pathogen reduction (i.e. fecal coliform bacteria) was fairly consistent between the seasons, with effluent fecal concentrations ranging from <10 cfu/100 mL to 2,760 cfu/100 mL (99.7% removal) with annual geometric means of 387 and 166 cfu/100mL. Overall the sand filters achieved levels of 200 cfu/100 mL fecal coliforms 81% of the time (26 of 32 sampling events) and 1,000 cfu/100 mL fecal coliforms 91% of the time (29 of 32 events). These were the best systems for 2003 in terms of fecal coliform removal and were somewhat better than their long-term performance (7 years and 254 effluent samples). Since 1996, their effluent fecal concentrations have been <200 cfus/100 mL for 74% of the time in summer and 40% in winter; 84% of the time they were <1000 cfu/100 mL in summer and 66% of time in winter (Table17). The 200 and 1000 cfu/100 mL are not actual effluent standards but rather are commonly accepted recreational bathing standards for freshwater and saltwater, respectively, and are only used here for illustrative reasons since the effluents are discharged into subsurface trenches, not public water bodies.

2. Peat filters: in-ground

The peat filters also produced better than “secondary” effluent quality, with ~ 95% BOD removal to 8-13 mgBOD/L and ~ 91% TSS removal to <5 mgTSS/L. Mean (geometric) annual effluent fecal coliform concentrations were 190 and 1246 cfus/100 mL, respectively for the two filters. Phosphorus removal was low at ~ 12% but total-N removal was the highest of any of the NERCC systems in 2003 at 55% for each of the filters. Ironically, this N-removal was probably due to the gradual hydraulic failure and saturation of the filters. Effluent DO levels averaged 2-3 mgO_2/L and values were often <2 mgO_2/L at the tipper bucket outlet where some oxygen diffusion is unavoidable. The peat filters historically were good nitrification reactors with high conversion of ammonium to nitrate and moderate N-removal (~20 %, Monson Geerts et al. 2000, 2001a). However, as the peat ages and subsides, the filters become increasingly saturated and less aerobic. Presumably, they then act as a mixed aerobic/anaerobic reactor with significant coupled nitrification-denitrification within the filter and improved total-N removal, although effluent ammonium concentrations would tend to be higher than in the fully aerobic state. In fact, decreasing DO and increasing ammonium-N were evident after early April 2003 and the west unit (#2) flow rate was reduced to about half the design rate for the period April - December. Another problem that occurred for the West filter (Replicate #2) in August 2003 was a failed timer that took about a month to repair.

Neither peat filter failed hydraulically to the surface although reduced performance was quite apparent.at any time. Based on our experiences with these systems since 1996, the best single indicator of potentially imminent hydraulic failure is low DO - values less than about 3 mgO_2/L. This is an easy to perform field measurement if the system has an appropriate place to monitor effluent DO without introducing air into the system, but requires routine monitoring to be most effective.

A more obvious indicator of hydraulic failure, but one requiring an analytical lab and trained sample collector, was the relatively poor fecal coliform bacteria removal during failure. Historically, properly functioning peat filters removed fecals to the routine detection limit of <5 cfu/100 mL with log removal rates >4 (>99.99%) for fecals, spiked *Salmonella,* and spiked MS-2 bacteriophage virus (Monson Geerts et al. 2001a; Pundsack et al. 2001, 2004; Olson et al. 2004a). However, although pathogen removal was lower than expected, it was still ~ 99% over the entire year (Table 11). The performance decline was evident in May 2003 for the East filter (Table 2) and from the beginning in the West filter. Effluent fecals for both filters combined were 50% for the 1000 cfu/100 mL "criterion" and 30% for the 200 cfu/100 mL "criterion." However, over the longer-term since 1995 (7+ years and 224 effluent samples), the peat filters have outperformed all other systems in terms of fecal coliform disinfection with removal to <200 cfus/ mL more than 81% of the time and to <1000 cfus/100 mL for more than 88% of the time, irrespective of season (Table 17). Little variation was seen between winter and summer months. The poorer performance in 2003 was presumably associated with its year-long period of activity prior to the 2003 study.

3. Modular peat filters

The Irish Peat modular peat filter at a mean flow of 246 gal/day, performed similarly to the sand filters (which were operated at similar mean flows of 226-246 gal/day) in removing organic matter (99% BOD), solids (99% TSS), and pathogens (99.9% fecal coliform bacteria). Effluent concentrations were more than an order of magnitude below secondary wastewater treatment levels with mean annual concentrations of 3 mg BOD/L, <1 mgTSS/L, and 20 fecal cfu/100 mL. However, the system removed substantially less phosphorus (6% TP,) than the sand filters. The overall rate of nitrogen removal was ~31% for the year and the remaining nitrogen was almost entirely in the form of nitrate with ammonium levels reduced to ~ 0.1 mgN/L on average. This high rate of nitrification was consistent with the relatively high levels of oxygen in the effluent (3~7 mg/L) and indicates that the system is aerobic when functioning properly. This filter reduced fecals to <1000 cfu/100mL 100% of the time and <200 for 81% of the samplings in 2003 which was the best disinfection performance of any system in 2003.

The data set for modular peat filters only extends through parts of three years but suggests excellent disinfection spanning a number of years (Tables 15A, 15B, 17). This system disinfected better than all of the other systems in 2003 with removal 81% of the time to <200 cfu/mL and 100% of the time to<1000 cfu/mL over the entire year. Combining these data with our three previous years, the removal to <200 cfu/mL was 90% in summer and 35% in winter; for removal to <1000 cfu/mL the values were 97% and 61% for summer and winter, respectively.

The Minnesota Peat modular peat filter, at a similar average flow of 226 gal/day, was less effective in treatment efficiency than its Irish counterpart, likely due to the significant subsidence/loss of peat (~30% by volume) and near saturation in all 3 modules, observed in September 2003. The peat had "subsided" several inches below the distribution network, and evidently wastewater intermittently was ponding at the peat surface to form an observed biomat. This would likely reduce treatment performance by "short circuiting." However, the filter still performed at a high level by removing 97% BOD, 95% TSS and >98% fecals to produce a mean annual effluent with 6 mgBOD/L, 2 mgTSS/L, and 438 fecal cfus/100 mL.

Total-P removal was also low (~7%) and overall N performance was somewhat lower than for the Irish Peat filled filter. Mean effluent oxygen was still aerobic (3.7 mg/L) but many samples had <2 mgO_2/L as a result the mean annual effluent ammonium concentration was much higher, 12 mgN/L) than for the other modular peat filter.

The Minnesota Peat filter reduced fecals to <1000 cfu/100mL 67% of the time and <200 for 40% of the samplings which was poorer than its long-term performance. Since 1998 (54 samples from 4 different years), the filters removed fecals to <200 cfu/mL for 42% of the summer samplings, but only 7% of the winter samplings. Corresponding summer and winter values for removal to <1000 cfu/mL were 69% and 41% respectively (Table 17). Clearly the Irish peat outperformed the Minnesota peat although the latter still removed >99.9% of the influent fecals over the 4 year period.

4. Constructed wetlands

The subsurface flow wetlands froze over the first winter period in 2003 and data was only available after May. It is not clear to what extent their lack of maintenance in late 2001 and all of 2002 contributed to their freezing. Freezing problems in previous winters with low snowfall (Reed et al. 2001) as in 2002/2003 led to our adding a six inch layer of peat in 2001 but this should be checked annually and augmented periodically, especially if flows are low or intermittent in early winter as was the case in 2002.

At flows of 157-172 gal/day from June-Dec 2003, the CWs removed 83% BOD, 93-95% TSS, 9-13% TP, 15-20% TN and 96-99.1% fecal coliform bacteria. The lower than anticipated annual flows were caused by a timer malfunction in October 2003. Effluent quality was nearly at secondary levels with mean annual values of ~35 mg BOD/L, 4 mg TSS/L and 1677/1183 fecal cfu/100 mL. Unlike the other systems, effluent dissolved oxygen indicated anaerobic conditions during most samplings and this was consistent with the absence of nitrate in the effluent (<0.01 mg N/L). It must also be noted that the removal data for 2003 are based on concentrations and therefore, underestimate the true performance of the wetland during summer when outflows are substantially reduced (on occasion to zero for much of day) due to plant evapotranspiration. This effect concentrates pollutants in the effluent and greatly underestimates their actual mass removal due to the greatly reduced flow. Despite being frozen for nearly half of the 2003 study year, the constructed wetlands reduced fecals to <5000 cfu/mL for all samplings, <1000 cfu/100mL for 60% of the samplings and <200 cfu/100 mL for 40% of the samplings.

Over the long-term, since 1996 (7 years and 198 effluent samples), the CWs performed much better than in 2003 with summer removals to <200 cfu/100 mL 45% of the time and to <1000 cfu/100 mL 70% of the time. Their winter performance dropped substantially however, with removal to <200 cfu/100 mL only 7% of the time and to <1000 cfu/100 mL ~ 20% of the time (Table 17). The stronger seasonal disinfection pattern for the CWs suggests that the removal mechanism may be dominated by biological processes. This is consistent with seasonality of BOD_5 and nitrogen removal. However, there were also freeze-up or partial freezing problems in at least 3 winters that would have reduced bed volume, thus decreasing retention time and decreasing removal efficiencies for various pollutants. Overall, the CWs have removed~99.8% of their fecal coliform bacteria load since 1996.

Additional microbial removal information for the sand, in-ground peat and CWs may be found in Pundsack et al. (2001, 2004) for *Salmonella* and fecals removal and Olson et al. (2004a,b) for virus and fecal coliform removal.

5.Textile filter (modular, recirculating):
The textile filter performed reasonably well in removing organic matter (97% BOD) and pathogens (99.98% removal fecal coliform bacteria) at a flow of 248 gal/day. Secondary level effluent quality was produced consistently throughout the year with means of 6 mgBOD/L, 7 mgTSS/L and a geometric mean of 101 fecal cfus/100 mL. As expected phosphorus removal was low (7%) because there was no adsorbent. N-removal was also relatively low at 21% but the filter nearly entirely removed ammonium after May by nitrifying it to nitrate. The filter remained aerobic throughout the year with DO levels always $\geq$ 3 mgO_2/L. This filter reduced fecals to <1000 cfu/100mL for 92% of the samplings and <200 for 64% which was generally similar to its two previous years of operation (Tables 16 and 17). Overall, its summer removal to <200 cfu/mL was 56% in summer and 13% in winter. Removal to <1000 cfu/mL increased to 73% in both summer and winter. The textile filter typically removed >99.5% of the influent fecal coliform bacteria for the entire period of record since 1999. A polishing sand filter further improved the system's efficiency to >99.9% for fecals in 1999-2000 but eventually failed (i.e. it ponded) due to undersizing.

IV. Treatment system effluents - comparison to previous years
The in-ground sand and peat filters and the constructed wetlands had been operated for 6 years previous to the 2002 shutdown and the modular peat and textile filters had also been operated for 3-4 years prior to 2003. Tables 11-16 summarize the entire record for the in-ground sand and peat filters, the modular peat filters, the textile filter and the constructed wetlands. Pollutant removal efficiencies are also shown as time series for the longer -lived systems, the sand and peat filters and the CWs in Figures 12-14. It is important to note that these summaries might be considered conservative from a design or risk assessment perspective since they include periods of data when system problems were occurring, such as when the original peat filters began to fail hydraulically after their first year (associated with their gravity distribution system that was changed to a pressure system; Monson Geerts et al., 2000, 2001a), when the sand filters were loaded at higher flow rates and one failed in Spring/Summer 2000 (after March 2000 when loading rates were increased by 33-100%, McCarthy and Monson Geerts, 2003) and when the constructed wetlands were impacted by freezing and rainstorm-related flushing, both of which reduce their retention time (Henneck et al., 1999, 2001; Axler et al. 2001; Kadlec et al. 2003).

A major objective of this project was to run the systems for an additional year and to then combine the 2003 data with historical data for ease of use by designers and regulators. Although a detailed analysis of these summary data is beyond the scope of this project, we have summarized the pathogen indicating fecal coliform concentration data in Table 17 and made the following observations regarding system performance in 2003 relative to previous years:

1. Sand filters: in-ground, single-pass

- Performance in 2003 was similar to that over the period 1996-2000 for comparable rates of hydraulic and organic matter loading (higher loading rates were applied in 2001 and the systems were idle in 2002)

2. Peat filters: in-ground, single-pass

- Despite indications that both peat filters were beginning to hydraulically fail, early in 2003, overall performance for TSS, BOD, TP and TN was similar to previous years (although the loading rate was decreased by ~50% for one system to determine if reduced loading would improve treatment performance).

- However, the removal efficiency for fecal coliform indicator bacteria was 1-2 orders of magnitude lower in 2003 than in previous years, although still ~ 99%. This was likely due to possible shortcutting ("channeling") associated with consolidation of the peat after 5 previous years of loading.

3. In-ground, modular peat filters:

- Performance in 2003 for both the Minnesota Peat and Irish Peat systems was similar to that during the initial testing periods of June 1999-Jun 2001 and September 1999 - June 2001, respectively, for comparable rates of hydraulic and organic matter loading. Although the systems were idle in 2002, the mean fecal coliform levels in their effluents were lower than for previous years.

4. Constructed wetlands:

- Overall performance was generally similar to that measured in previous years for BOD, TSS, TP and fecal coliforms. Despite an extended period without use, Fall 2001 to Spring 2003, the wetlands continued to function in a largely anaerobic mode, and so N removal remained lower than originally anticipated. For 2003, N removal was actually lower than either the sand or peat filters. The wetlands also froze over the winter indicating that the 6 inch layer of insulating peat added for winter 2000/2001 was insufficient for long-term insulation. However, the systems were fallow until late November 2002 and so the lack of heat input from continuous wastewater inflow may have contributed to the freezing that occurred mid-winter.

5. Recirculating modular textile filter:

- Performance in 2003 was generally similar to that measured previously for the period November 2000 - April 2001 (McCarthy et al. 2001a). Performance was also notably improved during the summer months in 2003 but there is not comparable data from previous summers. There were no apparent negative effects from the year without operation.

V. Operation and Maintenance

A limited number of problems are expected over the life of onsite treatment systems, ranging from outside influences, such as simple power outages and lightening strikes, homeowner abuse to the system, climate related problems from floods and cold snaps, to design and construction flaws. Because of the accessibility of the NERCC Demonstration Site to the NRRI building (11 miles), the systems were checked or monitored regularly (typically weekly). When problems occurred, they were usually discovered in a timely fashion and corrected within a few days, limiting reduced treatment performance of the systems. There were no major problems during this study other than the previously mentioned wetlands freezing (Table 18) and the indications that the in-ground peat filters, were beginning to fail hydraulically and would likely require partial to full peat replacement before operating them for another year. The research now seems to indicate that the peat in an in-ground filter, using Minnesota peat, would need to be replaced every 4-5 years.

Specific recommendations for system maintenance are included in previous NRRI technical reports. Journal manuscripts describing the NERCC treatment systems for previous years were cited previously in this report and many are downloadable from the following website:

http://septic.coafes.umn.edu/Research/index.html
(also linked from ***http://duluthstreams.org*** and

http://www.co.st-louis.mn.us/publichealth/Environmental/envir_pro_septic.htm).

Operation and maintenance (O/M) procedures are essential to maintain optimal performance of any onsite wastewater treatment system. Like a car, the system needs to be operated properly and periodically maintained by qualified personnel, to ensure that the system will work to treat wastewater generated in the home and recycle it back into the environment. Although maintenance requirements are fairly simple, it needs to be done on a routine basis. With proper operation by the homeowner and ongoing maintenance by a qualified service provider, the onsite sewage treatment system should last a long time. Without it, the system will break, much like a car if not properly maintained. An O/M manual should be supplied, and adhered to, with any pre-engineered or designed system.

The following are some basic maintenance and monitoring requirements that need to be considered for single-pass filter systems, grouped by system component: septic and pump tanks, control panel, pump and associated controls, and the filter. Additional recommendations for constructed wetlands may be found in Henneck et al., 1999, Henneck et al., 2001 and Wallace et al., 2001.

1. Septic Tank and Pump Tank

- Flow to the system (water meter in the house)
- Wastewater levels in the tanks
- Water tightness of tanks, risers, and pipe connections at tanks
- Septic tank outlet screen or screened pump vault for clogging
- Condition of tank baffles
- Sludge and scum levels in the septic tanks
- Sludge and grease presence in the pump tank

2. Control Panel and Controls

- Pumping frequency from pump counters and elapsed run time meters
- Operation of pumps, floats, valves, electrical controls and alarms
- Pump delivery rate (draw down test)
- Dosing volume and measure or calculate average pump run time

3. Sand, Peat, Textile Filters

- Inspect for ponding on the surface
- Check for biomat
- Peat - check for and track consolidation; should be somewhat "fluffy", retaining its original characteristics and not be overly wet
- Verification of equal spray/squirt height of orifices on each lateral
- Distribution lateral flushing if necessary
- Unusual odor
- Insect infestations
- Sample of filter effluent to check for clarity and odor or analyzed as specified in an Operating Permit (i.e. dissolved oxygen and/or BOD_5)

- Appropriate measures must be taken to protect the systems from freezing (Table 18). Information should be available from a certified contractor as well as from the National Small Flows Clearing House (URL above), the St. Louis County Onsites website (given previously) , and the Minnesota Extension Service Onsite Septic Systems Website (also given previously). Recent winters with relatively small amounts of snow cover have created conditions extremely favorable to freeze-up of many components of septic systems and additional insulation is a prudent recommendation for all systems.

- Go to the Bord-na-Mona website for more detailed information for maintaining modular peat filters: ***http://www.bnm.ie/environmental/small_scale_wastewater_treatment/puraflo.htm***

- Go to the OSI (Orenco) website at ***http://www.orenco.com/ots/ots_index.asp*** for more detailed information for maintaining modular textile filters and sand filters.

- The University of Minnesota Extension Service, the National Small Flows Clearinghouse (NSFC) and the EPA websites offer additional valuable information. Specific URLs are:

  - U. of Minnesota Extension Service: ***http://septic.coafes.umn.edu/index.html***

  - NSFC- ***http://www.nesc.wvu.edu/nsfc/nsfc_index.htm***

  - EPA- Septics: ***http://cfpub.epa.gov/owm/septic/home.cfm***

U.S. Environmental Protection Agency

4. <u>Constructed wetlands (horizontal subsurface flow)</u>

- As above regarding ponding, odors, and appropriate monitoring of the dosing pump, and inlet and outlet structures, and other conditions specified in the Operating Permit.

- Appropriate measures must be taken to protect the CWs from freezing (see Table 18). Information should be available from a certified contractor as well as from the National Small Flows Clearing House (URL above), the St. Louis County Onsites website (given previously) , and the Minnesota Extension Service Onsite Septic Systems Website (also given previously).

- Establishment of vegetation is important and may require multiple plantings and a mixture of plants should be considered; limited harvesting of plants may be desirable for aesthetic reasons and the vegetation may be used for additional insulation..

- Sizing and substrate size are very important and decreased winter performance should be considered.

- Although horizontal subsurface flow systems are the simplest of CWs to operate and except for freezing, the easiest of the alternative systems to maintain, more complex engineered systems such as vertical flow or forced bed aeration (e.g. the NAWE system at ***www.nawe-pa.com/tech/***), or coupled CW-Sand/peat filter systems, should be considered where wastewater strength is higher than average or increased nitrogen removal is required. However, these would require considerably more management.

This list is not meant to be all inclusive of required operation, maintenance and monitoring of a filter or constructed wetland system. The most up-to-date literature should be consulted in preparing operating permits for individual systems for both residential and commercial applications.

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Table 1. NERCC septic tank influent to alternative treatment systems, Nov 2002-Dec 2003, n=16 sample events. NO3-N = [NO3-N]+ [NO2-N].

	Flow (gal/day)	T (°C)	EC25 (uS/cm)	D.O. (mg/L)	BOD_5 (mg/L)	TSS (mg/L)	TP (mg/L)	TN (mg/L)	NH4-N (mg/L)	NO3-N (mg/L)	Fecals (cfu/100 mL)
22-Nov-02											
13-Dec-02											
10-Jan-03											
24-Jan-03											
29-Jan-03		12.4	1219	0.20	224	31	16.5	72.5	71.73	0.03	126000
19-Feb-03		12.4	1285	0.16	274	34	16.0	74.8	71.2	0.07	245000
12-Mar-03		11.6	1197	0.25	212	32	10.9	-	-	-	104500
02-Apr-03		12.1	1155	0.18	225	34	16.0	-	-	-	74000
23-Apr-03		12.1	1202	0.28	213	50	12.2	-	-	-	155500
14-May-03		13.8	1240	0.23	304	36	11.9	78.6	76.7	0.04	195000
04-Jun-03		14.7	1337	0.04	253	53	12.8	90.3	82.3	0.88	245000
25-Jun-03		17.5	1172	0.01	135	67	15.1	73.7	67.5	0.04	295000
16-Jul-03		19.9	1288	0.02	221	94	12.9	89.5	82.5	0.05	240000
06-Aug-03		19.8	1227	0.08	188	44	12.1	88.2	74.0	4.49	86000
27-Aug-03		21.2	1287	0.04	-	36	14.0	84.5	82.4	0.04	55000
17-Sep-03		20	1330	0.05	258	35	13.0	87.0	85.8	0.03	51000
08-Oct-03		18	1266	0.44	180	40	12.6	79.2	77.3	0.04	95500
30-Oct-03		17.1	1302	0.41	233	50	14.8	81.0	79.0		180250
19-Nov-03		16.2	1338	0.38	287	60	16.9	82.8	80.8	0.10	265000
10-Dec-03		14.3	1248	0.67	237	49	15.1	76.3	74.6	0.05	44000
Range		11.6-21.2	1155-1338	0.01-0.67	135-304	31-94	10.9-16.9	72.5-90.3	67.5-85.8	0.03-4.49	44000-295000
Median		15.5	1257	0.19	225	42	13.5	81.0	77.3	0.04	140750
Mean		15.8	1256	0.22	229	47	13.9	81.4	77.4	0.49	146842

Table 2. In-ground single-pass peat filter (Replicate #1 – East) effluent water quality. Nov 2002-Dec 2003, n=16 sample events. Total gallons treated Nov 22, 2002 – Dec 10, 2003 = 75,848 gallons septic tank effluent and total gallons treated from Jan 12, 1996 – Dec 10, 2003 = 430,278 gallons septic tank effluent. NOTE- TN = combined sample from both replicate filters (East+West). NO3-N = [NO3-N]+ [NO2-N].

	Flow (gal/day)	T (^oC)	EC25 (uS/cm)	D.O. (mg/L)	BOD_5 (mg/L)	TSS (mg/L)	TP (mg/L)	TN (mg/L)	NH4-N (mg/L)	NO3-N (mg/L)	Fecals (cfu/100 mL)
22-Nov-02	364										
13-Dec-02	288										
10-Jan-03	282										
24-Jan-03	217										
29-Jan-03	236	5.1	665	5.4	3	0.4	6.6	45	11	40	5
19-Feb-03	220	3.5	589	6.5	2	0.5	7.5	40	12	30	5
12-Mar-03	226	3.5	549	5.3	2	1.2	7.8	-	-	-	5
02-Apr-03	222	4.5	616	5.9	2	0.5	8.6	-	-	-	50
23-Apr-03	208	7.5	643	3.2	2	1.0	8.6	-	-	-	5
14-May-03	206	8.6	670	2.7	3	0.5	8.4	50	13	37	80
04-Jun-03	203	13.9	633	1.6	5	2.0	8.8	43	14	23	1120
25-Jun-03	198	15.1	675	1.7	7	5.6	10.7	41	19	14	2400
16-Jul-03	202	16.2	743	3.6	8	2.0	17.4	32	24	0.09	1830
06-Aug-03	28	19.8	685	0.9	26	5.0	32.4	22	16	0.14	20
27-Aug-03	147	18.9	677	2.2	-	2.8	12.4	28	16	7.7	2500
17-Sep-03	186	18.0	736	0.9	14	5.8	11.8	31	21	5.6	1500
08-Oct-03	216	15.0	706	2.1	14	2.4	11.2	39	24	5.6	1900
30-Oct-03	167	10.0	669	2.0	10	4.8	11.7	33	26	3.6	150
19-Nov-03	180	8.6	763	2.2	16	4.8	11.2	35	32	0.57	6800
10-Dec-03	145	6.6	759	3.9	16	8.8	15.6	32	32	0.04	1560
Range	28-364	3.5-19.8	589-763	0.9-6.5	2-26	<1-8.8	6.6-32.4	22-50	11-32	0.09-40	5-6800
Median	205	9.3	673	2.5	7.0	2.2	11.0	35	21	5.6	635
Mean	207	10.9	674	3.1	8.5	3.0	11.9	36	21	13	190

Table 3. In-ground, single-pass peat filter (Replicate #2 – West) effluent water quality, Nov 2002-Dec 2003, n=14 sample events. Total gallons treated Nov 22, 2002 – Dec 10, 2003 = 49,582 gallons septic tank effluent and total gallons treated from Jan 12, 1996 – Dec 10, 2003 = 429,703 gallons septic tank effluent. NOTE- TN = combined sample from both replicate filters (East+West). NO3-N = [NO3-N]+ [NO2-N].

	Flow (gal/day)	T (°C)	EC25 (uS/cm)	D.O. (mg/L)	BOD_5 (mg/L)	TSS (mg/L)	TP (mg/L)	TN (mg/L)	NH4-N (mg/L)	NO3-N (mg/L)	Fecals (cfu/100 mL)
22-Nov-02	260										
13-Dec-02	136										
10-Jan-03	310										
24-Jan-03	256										
29-Jan-03	258	5.2	744	2.8	10	7.2	8.4	45	30	5.4	3000
19-Feb-03	246	4.4	794	3.0	18	6.4	9.6	40	37	0.80	12500
12-Mar-03	190	3.0	864	4.3	21	8.4	11.0	-	-	-	1800
02-Apr-03	114	3.5	859	3.7	16	1.2	10.2	-	-	-	740
23-Apr-03	115	5.9	816	1.3	19	7.0	10.6	-	-	-	2700
14-May-03	114	8.4	838	1.8	3	4.4	15.2	50	36	9.8	900
04-Jun-03	111	15.3	864	1.6	17	6.8	10.7	43	39	5.6	5600
25-Jun-03	112	14.8	891	1.4	15	6.0	11.2	41	38	3.9	1900
16-Jul-03	113	15.8	822	3.7	20	3.0	16.4	32	31	0.06	1040
06-Aug-03	18	21.4	892	0.3	24	7.0	24.8	38	16	0.15	190
27-Aug-03	0	-	-	-	-	-	-	28	-	-	-
17-Sep-03	0	-	-	-	-	-	-	31	-	-	-
08-Oct-03	117	15.2	817	0.6	8	2.8	8.2	39	11	33	790
30-Oct-03	105	11.0	719	1.0	6	2.8	10.1	33	10	20	270
19-Nov-03	114	8.6	723	1.8	5	2.8	7.8	35	11	17	570
10-Dec-03	109	6.2	731	3.6	5	2.4	8.9	32	15	13	700
Range	0-310	3.0-21.4	719-892	0.3-4.3	5-21	1.2-8.4	8.2-24.8	31-50	11-39	0.06-33	190-12,500
Median	114	8.5	820	1.9	15.5	5.2	10.4	35	31	5.6	970
Mean	140	9.9	812	2.2	13.4	4.9	11.7	36	27	9.8	1246

Table 4. Modular peat filter (using Minnesota Peat) effluent water quality, Nov 2002-Dec 2003, n=16 sample events. Total gallons treated Nov 22, 2002 – Dec 10, 2003 = 85,273 gallons septic tank effluent and total gallons treated from Aug 6, 1998 – Dec 10, 2003 = 381,833 gallons septic tank effluent NO3-N = [NO3-N]+ [NO2-N].

	Flow (gal/day)	T (ºC)	EC25 (uS/cm)	D.O. (mg/L)	BOD_5 (mg/L)	TSS (mg/L)	TP (mg/L)	TN (mg/L)	NH4-N (mg/L)	NO3-N (mg/L)	Fecals (cfu/100 mL)
22-Nov-02	256										
13-Dec-02	240										
29-Jan-03	234	1.1	883	7.2	5	2.2	10.4	56	16	40	12700
19-Feb-03	247	0.7	871	6.1	9	2.4	12.5	51	22	30	8400
12-Mar-03	247	0.3	960	6.4	5	1.6	11.9	-	-	-	300
02-Apr-03	247	1.4	925	6.2	3	0.5	12.3	-	-	-	100
23-Apr-03	245	6.7	898	4.8	2	2.0	11.7	-	-	-	350
14-May-03	227	8.9	1032	4.6	12	0.5	13.5	81	19	58	160
04-Jun-03	200	14.1	947	2.1	7	3.2	14.7	80	8.4	59	2000
25-Jun-03	197	16.5	874	1.9	5	2.4	14.0	74	4.3	63	780
16-Jul-03	196	17.4	863	1.8	3	1.0	14.2	66	2.7	53	70
06-Aug-03	204	18.3	809	1.7	4	1.2	13.0	69	1.6	59	60
27-Aug-03	216	19.6	832	2.0	-	0.5	12.9	58	1.7	61	5
17-Sep-03	237	17.6	817	1.7	4	1.6	12.3	58	4.9	54	1180
08-Oct-03	247	13.4	842	2.4	4	3.2	12.0	63	6.5	57	-
30-Oct-03	125	10.1	941	2.0	27	8.8	13.0	75	21	52	10000
19-Nov-03	262	6.5	920	4.3	3	1.6	12.0	63	21	40	100
10-Dec-03	247	5.7	955	4.4	4	2.4	12.1	67	28	37	610
Range	125-262	0.7-19.6	809-1032	1.7-7.2	3-27	0.5-8.8	10.4-14.7	51-81	1.6-28	30-63	5-12700
Median	239	9.5	891	3.4	4.0	1.8	12.4	66	8.4	54	350
Mean	226	9.9	898	3.7	6.4	2.2	12.7	66	12	51	438

Table 5. Modular peat filter (using standard Irish peat) effluent water quality, Nov 2002-Dec 2003, n=16 sample events. Total gallons treated Nov 22, 2002 – Dec 10, 2003 = 94,390 gallons septic tank effluent and total gallons treated from Aug 6, 1998 – Dec 10, 2003 = 402,853 gallons septic tank effluent. NO3-N = [NO3-N]+ [NO2-N].

	Flow (gal/day)	T (°C)	EC25 (uS/cm)	D.O. (mg/L)	BOD_5 (mg/L)	TSS (mg/L)	TP (mg/L)	TN (mg/L)	NH4-N (mg/L)	NO3-N (mg/L)	Fecals (cfu/100 mL)
22-Nov-02	255										
13-Dec-02	250										
29-Jan-03	252	0.8	868	6.8	2	<1	10.8	49	4.5	45	670
19-Feb-03	250	0.5	883	6.6	2	<1	12.4	49	7.2	42	460
12-Mar-03	250	0.3	881	6.3	2	<1	11.4	-	-	-	250
02-Apr-03	252	1.6	869	6.5	2	1.2	12.0	-	-	-	160
23-Apr-03	251	5.6	828	4.7	2	1	11.9	-	-	-	10
14-May-03	252	9.8	866	6.6	2	<1	13.2	62	1.8	56	5
04-Jun-03	254	15.2	814	3.3	2	<1	13.6	61	0.10	54	5
25-Jun-03	252	16.6	846	3.1	2	<1	14.2	64	0.10	60	5
16-Jul-03	251	17.4	727	3.3	2	<1	14.4	57	0.10	52	5
06-Aug-03	250	19.0	751	3.9	2	<1	14.8	57	0.10	52	10
27-Aug-03	252	20.1	758	5.0	-	<1	12.2	49	0.10	52	5
17-Sep-03	252	18.1	783	3.5	2	<1	12.8	51	0.10	52	5
08-Oct-03	254	14.5	710	5.1	2	<1	12.5	51	0.35	53	5
30-Oct-03	127	9.9	902	6.0	2	<1	13.2	65	0.10	65	80
19-Nov-03	265	8.0	631	5.6	2	<1	12.0	54	0.65	56	5
10-Dec-03	251	5.9	858	5.4	2	<1	12.9		0.99	54	10
Range	127-265	0.5-20.1	631-902	3.1-6.8	2	<1-1.2	10.8-14.8	49-65	0.10-7.2	42-65	5-670
Median	252	9.9	837	5.2	2	0.5	12.7	54	0.12	53	10
Mean	246	10.2	811	5.1	2	0.6	12.8	56	0.12	53	20

Table 6. Sand filter (Rep # 1 –East) and treatment performance, Nov 2002-Dec 2003, n=16 sample events. Total gallons treated Nov 22, 2002 – Dec 10, 2003 = 71,925 gallons septic tank effluent and total gallons treated from Sept 27, 1996 – Dec 10, 2003 = 500,786 gallons septic tank effluent. NOTE- TN = combined sample from both replicate filters (East+West). NO3-N = [NO3-N]+ [NO2-N].

	Flow (g/day)	T (°C)	EC25 (uS/cm)	D.O. (mg/L)	BOD_5 (mg/L)	TSS (mg/L)	TP (mg/L)	TN (mg/L)	NH4-N (mg/L)	NO3-N (mg/L)	Fecals (cfu/100 mL)
22-Nov-02	293										
13-Dec-02	273										
10-Jan-03	283										
24-Jan-03	307										
29-Jan-03	273	3.0	878	5.8	3	<1	7.4	67	6.8	65	230
19-Feb-03	254	2.5	972	5.5	2	<1	9.1	71	5.6	72	5
12-Mar-03	240	2.1	1008	7.9	2	<1	10.0	-	-	-	10
02-Apr-03	211	2.0	978	6.2	2	<1	9.5	-	-	-	80
23-Apr-03	171	4.6	955	4.3	6	2	9.1	-	-	-	2760
14-May-03	160	7.7	1051	4.7	3	<1	9.0	92	4.6	90	5
04-Jun-03	168	12.9	985	3.2	5	2	8.0	85	0.82	83	2400
25-Jun-03	159	15.1	901	3.4	3	5	7.2	80	5.9	74	340
16-Jul-03	188	16.0	909	5.1	4	2	6.9	79	6.8	74	110
06-Aug-03	28	19.8	1150	8.9	2	4	4.3	103	0.34	106	220
27-Aug-03	153	18.5	1126	5.1	-	4	4.2	100	0.28	99	5
17-Sep-03	147	17.2	869	3.5	2	<1	4.8	72	0.10	72	5
08-Oct-03	180	14.4	840	6.2	2	<1	5.3	69	0.10	65	5
30-Oct-03	158	11.9	839	5.0	2	5	5.8	67	0.14	64	5
19-Nov-03	169	8.6	800	4.8	2	<1	5.4	64	2.2	57	5
10-Dec-03	160	6.2	904	7.1	2	<1	6.1	66	2.0	69	5
Range	28-307	2.0-19.8	800-1150	3.2-7.1	2-6	<1-5	4.2-10.0	64-103	0.10-6.8	64-106	5-2760
Median	171	10.3	932	5.1	2	<1	7.1	72	2.0	72	7.5
Mean	193	10.2	948	5.4	2.5	1.8	7.0	78	2.7	76	34

Table 7. Sand filter (Rep # 2 –West) effluent water quality, Nov 2002-Dec 2003, n=16 sample events. Total gallons treated Nov 22, 2002 – Dec 10, 2003 = 74,110 gallons septic tank effluent and total gallons treated from Sept 27, 1996 – Dec 10, 2003 = 579,753 gallons septic tank effluent. NOTE- TN = combined sample from both replicate filters (East+West). NO3-N = [NO3-N]+ [NO2-N].

	Flow (gal/day)	T (^oC)	EC25 (uS/cm)	D.O. (mg/L)	BOD_5 (mg/L)	TSS (mg/L)	TP (mg/L)	TN (mg/L)	NH4-N (mg/L)	NO3-N (mg/L)	Fecals (cfu/100 mL)
22-Nov-02	265										
13-Dec-02	263										
10-Jan-03	250										
24-Jan-03	227										
29-Jan-03	231	2.7	809	7.1	3	<1	6.0	67	0.88	61	90
19-Feb-03	211	2.3	871	5.7	2	<1	7.2	71	3.4	60	2100
12-Mar-03	201	2.0	850	7.7	2	<1	7.3	-	-	-	20
02-Apr-03	196	3.2	825	6.5	4	<1	7.7	-	-	-	5
23-Apr-03	186	5.4	927	4.8	2	1	8.1	-	-	-	20
14-May-03	190	8.6	943	3.6	2	<1	8.4	92	2.2	81	5
04-Jun-03	186	14.9	981	2.9	2	<1	7.7	85	0.50	83	100
25-Jun-03	182	15.0	882	2.7	2	1.2	7.2	80	2.8	73	150
16-Jul-03	189	16.4	863	5.8	2	<1	7.2	79	3.4	71	30
06-Aug-03	26	19.6	1008	6.5	2	<1	4.3	103	0.11	91	10
27-Aug-03	190	18.7	1048	5.9	-	<1	5.4	100	0.20	93	10
17-Sep-03	188	17.5	867	3.7	2	<1	5.5	72	0.10	71	5
08-Oct-03	221	14.2	919	4.3	2	<1	6.0	69	0.40	77	5
30-Oct-03	193	12.1	927	4.5	2	<1	6.9	67	0.11	74	5
19-Nov-03	215	8.6	900	5.5	2	<1	7.2	64	0.66	69	20
10-Dec-03	203	6.7	874	7.6	2	<1	7.5	66	0.92	64	90
Range	26-265	2.0-19.6	809-1048	2.7-7.7	2-4	<1-1.2	4.3-8.4	64-103	0.1-3.4	60-93	5-2100
Median	196	10.4	891	5.6	2	<1	7.2	72	0.66	73	20
Mean	196	10.5	906	5.3	2	<1	6.9	78	1.2	74	25

Table 8. Subsurface flow constructed wetland (Rep # 1, both cells) effluent water quality, Nov 2002-Dec 2003, n= 10 sample events. NO3-N = [NO3-N]+ [NO2-N].

	Flow (gal/day)	T (°C)	EC25 (uS/cm)	D.O. (mg/L)	BOD_5 (mg/L)	TSS (mg/L)	TP (mg/L)	TN (mg/L)	NH4-N (mg/L)	NO3-N (mg/L)	Fecals (cfu/100 mL)
22-Nov-02											
13-Dec-02											
10-Jan-03											
24-Jan-03											
29-Jan-03	Frozen										
19-Feb-03	Frozen										
12-Mar-03	Frozen										
02-Apr-03	Frozen										
23-Apr-03	Frozen										
14-May-03	Thawed										
04-Jun-03	236	6.7	1197	0.03	106	2.4	11.4	59	61	<0.01	4000
25-Jun-03	179	14.5	1331	0.06	76	4.4	14.8	72	68	<0.01	4900
16-Jul-03	216	14.3	1210	2.35	N/S	N/S	14.8	76	70	<0.01	210
06-Aug-03	201	16.9	1241	1.16	16	1.6	11.9	80	73	<0.01	180
27-Aug-03	219	17.8	1291	0.09	N/S	<1	11.5	75	76	<0.01	260
17-Sep-03	182	14.0	1241	0.38	16	1.6	11.6	73	72	<0.01	810
08-Oct-03	0*	17.3	1077	0.32	14	<1	10.3	63	63	<0.01	<10
30-Oct-03	93	8.8	1181	0.36	16	1.2	10	65	65	<0.01	330
19-Nov-03	204	5.6	1168	0.46	27	10	10.4	-	64	<0.01	3600
10-Dec-03	190	3.2	1307	0.81	20	4.4	13.6	72	75	<0.01	800
Range	93-236	0-17.8	1077-1331	0.03-2.3	14-106	<1-10	10-15	59-80	61-76	<0.01	<10-4900
Median	196	14.2	1226	0.37	18	2.4	11.6	72	69	<0.01	800
Mean	172	11.9	1224	0.6	36.4	3.7	12.0	71	69	<0.01	1677

* 10/08/03 No flow-timers/pumps off

Table 9. Subsurface flow constructed wetland (Rep # 2, both cells) effluent water quality, Nov 2002-Dec 2003, n= 10 sample events. NO3-N = [NO3-N]+ [NO2-N].

	Flow (gal/day)	T (^oC)	EC25 (uS/cm)	D.O. (mg/L)	BOD_5 (mg/L)	TSS (mg/L)	TP (mg/L)	TN (mg/L)	NH4-N (mg/L)	NO3-N (mg/L)	Fecals (cfu/100 mL)
22-Nov-02											
13-Dec-02											
10-Jan-03											
24-Jan-03											
29-Jan-03	Frozen										
19-Feb-03	Frozen										
12-Mar-03	Frozen										
02-Apr-03	Frozen										
23-Apr-03	Frozen										
14-May-03	Thawed										
04-Jun-03	209	9.1	1079	0.06	106	4	11.4	48	47	<0.01	1200
25-Jun-03	212	14.0	1296	0.04	78	8.8	16.8	67	64	<0.01	1500
16-Jul-03	194	13.9	1234	2.32	26	2	15.5	76	70	<0.01	140
06-Aug-03	179	N/D	1242	1.20	16	1.6	12.4	77	70	<0.01	130
27-Aug-03	179	18.0	1274	0.07	N/S	1.2	12.2	69	69	<0.01	120
17-Sep-03	151	14.8	1258	0.35	14	2.2	11.6	69	72	<0.01	170
08-Oct-03	0*	15.0	1079	0.20	12	<1	10.8	61	62	<0.01	<10
30-Oct-03	102	9.0	1169	0.35	16	2	9.9	65	64	0.03	2000
19-Nov-03	185	5.7	1173	0.43	29	11.8	10.8	65	65	<0.01	3100
10-Dec-03	161	3.3	1288	0.74	18	3.8	14	73	73	0.04	2290
Range	102-212	3.3-18.0	1079-1296	0.04-2.3	12-106	0.5-12	10-17	48-77	47-73	<0.01-0.04	5-3100
Median	179	13.9	1238	0.35	18	2	11.9	68	67	<0.01	1200
Mean	157	11.4	1210	0.58	35	4	12.5	67	66	<0.01	1183

*10/08/03 No flow-timers/pumps off

Table 10. Textile filter (single unit) effluent water quality, Nov 2002 -Dec 2003, N=14 sample events. Total gallons treated Nov 22, 2002 – Dec 10, 2003 = 70,000 gallons septic tank effluent and total gallons treated from June 29, 1999 – Dec 10, 2003 = 263,356 gallons septic tank effluent. NO3-N = [NO3-N]+ [NO2-N].

	Flow (gal/day)	Temp (°C)	EC25 (uS/cm)	D.O. (mg/L)	BOD_5 (mg/L)	TSS (mg/L)	TP (mg/L)	TN (mg/L)	NH4-N (mg/L)	NO3-N (mg/L)	Fecal s (cfu/100 mL)
22-Nov-02	346										
13-Dec-02	278										
10-Jan-03	366										
24-Jan-03	227										
29-Jan-03	212	3.7	1153	7.6	24	27	10.7	69	70	0.55	160
19-Feb-03	221	3.5	1167	6.2	16	10	11.3	66	66	0.66	610
12-Mar-03	82	3.9	1144	7.6	5	1	10.2	-	-	-	740
14-May-03	264	10.2	988	6.5	9	9	14.2	70	42	28	830
04-Jun-03	244	17.0	886	4.4	5	2	15.4	78	0.97	71	1450
25-Jun-03	268	18.4	874	2.9	2	<1	15.4	66	1.2	60	170
16-Jul-03	255	18.9	855	3.6	2	<1	13.0	73	1.8	65	150
06-Aug-03	277	20.4	787	3.6	2	<1	11.6	72	0.47	62	10
27-Aug-03	234	20.5	785	3.3	-	<1	12.0	59	0.12	56	50
17-Sep-03	272	18.9	838	3.9	3	<1	13.0	60	0.27	57	10
08-Oct-03	201	15.5	816	4.4	2	<1	12.2	63	0.10	57	20
30-Oct-03	250	10.0	855	4.6	2	<1	14.6	63	0.10	57	5
19-Nov-03	218	8.0	774	6.5	12	47	12.0	42	0.23	41	500
10-Dec-03	346	5.0	902	7.1	2	<1	13.0	65	0.26	59	20
Range	82-366	3.5-20.5	774-1167	2.9-7.6	2-24	<1-47	10.2-15.4	42-78	0.10-70	0.55-71	5-1450
Median	250	12.9	865	4.5	3.0	<1	12.6	66	0.47	57	155
Mean	248	12.4	916	5.2	6.4	7.1	12.8	65	14	47	101

Table 11. Average annual % removal rates for 9 onsite wastewater treatment systems tested in 2003 at the Northeast Regional Correction Center. N =16 sampling events Jan-Dec 2003; except N = 10 for the constructed wetlands which froze at the end of January 2003 and thawed in May 2003. Average percent removal based on: ((inflow conc.- outflow conc.)/inflow conc.) x 100 = % removed. ( ) indicates number of systems tested.

Onsite System	Flow (gal/day)	BOD_5	TSS	TP	TN	Fecal Coliform Bacteria
Sand Filters (2) (single pass, in-ground)	193 196	99 99	96 99	48 50	41 41	99.8 99.9
Peat Filters (2) (single-pass, in-ground)	207 140	96 94	94 88	12 13	55 55	98.9 98.8
Peat Filters (single-pass, modular) (1) *Irish peat* (1) *Minnesota peat*	246 226	99 97	99 95	6 7	31 19	99.9 98.4
Constructed wetlands (2) (subsurface flow, 2-cells)	172 157	83 83	95 93	13 9	15 20	96.0 99.1
Textile Filter (1 unit) (recirculating RX-30)	248	97	84	7	21	99.8

Table 12. Performance (all years) of NERCC in-ground, single-pass peat filters, 3/96-9/01 and 1/03-12/03.

NERCC Peat Filters

	WINTER (Nov. - Apr.)			SUMMER (May - Oct)		
Parameter	Inflow[1]	Outflow[2]	% - Removal[3]	Inflow[1]	Outflow[2]	% - Removal[3]
Q (gal/d)	185			191		
BOD_5 (mg/L)	269 (64)	10.5 (14.1)	96	221 (84.4)	7.5 (11.4)	96
TSS (mg/L)	43 (13)	2.6 (2.9)	93	48 (17.2)	2.3 (2.2)	94
TP (mg/L)	13.4 (2.9)	8.8 (3.9)	32	13.0 (3.7)	9.6 (4.8)	22
TN (mg/L)	84.1 (18)	48.2 (27.8)	43	77.1 (19.7)	51.7 (22.0)	33.6
NH_4-N (mg/L)	75.8 (14.8)	14.1 (7.8)	80	69.3 (18.2)	19.5 (11.6)	70
NO_3-N (mg/L)	0.03 (0.02)	34.8 (34.1)	Nitrification	0.15 (0.69)	32.1 (27.4)	Nitrification
fecal coliforms[3]	$3.7x10^5$	522	99.86	$2.0x10^5$	194	99.90

N=57 winter, N=50 summer;
[1]average during the seasonal period (Standard Deviation);
[2] mean percent removal based on: ((inflow-outflow)/inflow) x 100 = %
[3]geometric mean colony-forming units (cfu) per 100mL

Table 13. Performance (all years) of NERCC in-ground, single-pass sand filters, 3/96-9/01 and 1/03-12/03.

	NERCC Sand filters (East and West)					
	WINTER (Nov. - Apr.)			SUMMER (May - Oct.)		
Parameter	Inflow[1]	Outflow2	% - Removal[3]	Inflow[1]	Outflow[2]	% - Removal[3]
Q (gal/d)	262			246		
BOD_5 (mg/L)	261 (57)	11.7 (20.9)	96	243 (77.6)	7.5 (13.6)	97
TSS (mg/L)	44 (13)	5.0 (7.9)	88	48 (18.5)	3.7 (5.5)	92
TP (mg/L)	13.7 (2.6)	7.8 (2.6)	42	13.3 (3.3)	6.6 (3.0)	48
TN (mg/L)	83.9 (16.5)	69.6 (18.7)	16	82.1 (15.3)	69.1 (22.4)	13
NH_4-N (mg/L)	76.1 (13.9)	13.4 (13.9)	82	73.8 (14.0)	7.5 (13.2)	90
NO_3-N (mg/L)	0.03 (0.03)	56.5 (27.6)	Nitrification	0.14 (0.68)	63.0 (24.3)	Nitrification
fecal coliforms[3]	$2.8x10^5$	217	99.92	$2.5x10^5$	68	99.97

N=50 winter, N=46 summer

[1]average during the seasonal period (Standard Deviation)

[2] mean percent removal based on: ([inflow-outflow]/inflow) x 100 = % removed

[3]geometric mean colony-forming units (cfu) per 100mL

Table 14. Performance (all years) of NERCC constructed wetlands, 3/96-9/01 and 6/03-12/03.

NERCC constructed wetlands (cells 1 and 2)

	WINTER (Nov. - Apr.)			SUMMER (May - Oct.)		
Parameter	Inflow[1]	Outflow[1]	% - Removal[2]	Inflow[1]	Outflow[1]	% - Removal[2]
Q (gal/d)	207			216		
BOD_5 (mg/L)	268 (57)	55.2 (41.9)	79	230 (91)	22.8 (18.1)	88.2
TSS (mg/L)	44 (13)	9.1 (4.6)	76	48 (19)	7.7 (6.3)	81.7
TP (mg/L)	13.7 (2.6)	9.9 (3.3)	25	13.4 (3.3)	8.8 (5.0)	36
TN (mg/L)	86 (13)	64.2 (16.1)	24	81.4 (14.3)	52.4 (21.3)	34
NH_4-N (mg/L)	77.1 (12)	59.9 (16.4)	22	74(14)	53.2 (21.2)	29
NO_3-N (mg/L)	0.03 (0.02)	0.48 (2.1)	nitrification	0.13 (0.63)	0.22 (0.33)	nitrification
fecal coliforms[3]	$4.0x10^5$	6487	98.3	$2.3x10^5$	369	99.8

N=50 winter, N=46 summer

[1]average during the seasonal period (" Standard Deviation)

[2] mean percent removal based on: ((inflow-outflow)/inflow) x 100 = % removed

[3]geometric mean colony-forming units (cfu) per 100mL

Table 15A. Performance (all years) of modular peat filter (using Minnesota Peat), 7/98-5/01 and 1/03-12/03. There was no flow from 6/99-8/99 due to ponding.

	NERCC modular peat filter using Minnesota Peat (MSI)					
	Winter (Nov. - Apr.)			Summer (May - Oct.)		
Parameter	Inflow[1]	Outflow[1]	% - Removal[2]	Inflow[1]	Outflow[1]	% - Removal[2]
Q (gal/d)	289			211		
BOD_5 (mg/L)	265 (75.1)	11.8 (13.4)	90	225 (76.1)	11.7 (22.9)	92
TSS (mg/L)	44.1 (15.2)	4.4 (3.5)	84	52.1 (17.8)	3.4 (2.5)	92
TP (mg/L)	14.0 (3.4)	11.9 (3.0)	13	14.3 (3.4)	12.4 (2.5)	5
TN (mg/L)	80.9 (24.8)	54.8 (20.7)	32	75.1 (27.9)	48.2 (27.4)	25
NH_4-N (mg/L)	74.2 (21.1)	20.5 (26.9)	76	65.9 (28.0)	10.7 (21.3)	84
NO_3-N (mg/L)	0.03 (0.03)	36.4 (17.9)	nitrification	0.18 (0.76)	36.1 (23.5)	nitrification
fecal coliforms[3]	$3.5x10^5$	2468	99.3	$2.4x10^5$	396	99.8
EC25 (umhos)	1128 (322)	749 (285)		1136 (299)	662 (309)	
Temp. (°C)	12.5 (1.6)	3.9 (2.6)		17.3 (4.3)	13.4 (6.0)	
pH	7.3 (0.1)	6.4 (0.7)		7.2 (0.1)	4.1 (2.9)	
DO (mg/L)	0.4 (0.4)	4.6 (3.1)		0.3 (0.5)	2.6 (2.5)	

N=30 winter, N=28 summer

[1]average during the seasonal period (Standard Deviation);

[2] mean percent removal based on: ((inflow-outflow)/inflow) x 100 = % removed;

[3]geometric mean colony-forming units (cfu) per 100mL.

Table 15B. Performance (all years) of NERCC modular peat filter (using Irish Peat), 7/98-5/01 and 1/03-12/03.

	NERCC modular peat filter using Irish Peat					
	Winter (Nov. - Apr.)			Summer (May - Oct.)		
Parameter	Inflow[1]	Outflow[1]	% - Removal[2]	Inflow[1]	Outflow[1]	% - Removal[2]
Q (gal/d)	287			223		
BOD_5 (mg/L)	265 (75.1)	6.6 (7.7)	94	225 (76.1)	6.1 (11.1)	94
TSS (mg/L)	44.1 (15.2)	3.7 (4.6)	88	52.1 (17.8)	2.1 (2.7)	96
TP (mg/L)	14.0 (3.4)	12.4 (3.2)	10	14.3 (3.4)	14.0 (3.7)	0
TN (mg/L)	80.9 (24.8)	52.6 (16.4)	34	75.1 (27.9)	55.9 (17.8)	28
NH_4-N (mg/L)	74.2 (21.1)	15.8 (17.5)	79	65.9 (28.0)	2.6 (5.2)	96
NO_3-N (mg/L)	0.03 (0.03)	37.2 (16.8)	nitrification	0.18 (0.76)	52.9 (17.8)	nitrification
fecal coliforms[3]	$3.5x10^5$	531	99.8	$2.4x10^5$	28	99.99
EC25 (umhos)	1128 (322)	748 (216)		1136 (299)	759 (170)	
Temp. (°C)	12.5 (1.6)	4.1 (2.6)		17.3 (4.3)	16.1 (3.6)	
pH	7.3 (0.1)	6.4 (0.4)		7.2 (0.1)	5.9 (0.6)	
DO (mg/L)	0.4 (0.4)	4.8 (3.0)		0.3 (0.5)	3.1 (2.6)	

N=30 winter, N=34 summer

[1]average during the seasonal period (Standard Deviation);

[2] mean percent removal based on: ((inflow-outflow)/inflow) x 100 = % removed;

[3]geometric mean colony-forming units (cfu) per 100mL.

Table 16. Performance (all years) of NERCC textile filter, 7/99-5/01 and 1/03-12/0. The system was inactive from 12/22/99-5/17/00. Note- there is data for the performance of this system coupled to a polishing sand filter that received its effluent but there were problems with the sand filter. Therefore, we did not include those data here. A polishing sand filter would be expected to further improve BOD5, TSS and fecal coliform removal, and further convert effluent NH4-N to NO3-N via nitrification as long as the filter remains aerobic. Additional removal of TN and TP would occur but the improve would be relatively small.

NERCC textile filter

	Winter (Nov. - Apr.)			Summer (May - Oct.)		
Parameter	Inflow[1]	Outflow[1]	% - Removal[2]	Inflow[1]	Outflow[1]	% - Removal[2]
Q (gal/d)	234			254		
BOD_5 (mg/L)	239 (41.8)	7.5 (6.7)	97	212 (67.1)	6.6 (8.9)	98
TSS (mg/L)	39.6 (9.8)	7.5 (12.9)	82	49 (18.4)	4.3 (5.1)	92
TP (mg/L)	14.2 (2.5)	11.6 (1.6)	16	13.4 (3.3)	12.0 (3.0)	3
TN (mg/L)	65.2 (23.3)	51.1 (23.7)	20	69.9 (25.3)	57.9 (18.6)	21
NH_4-N (mg/L)	67.1 (11.6)	14.7 (22.2)	78	63.8 (23.3)	6.2 (9.6)	92
NO_3-N (mg/L)	0.04 (0.03)	28.7 (20)	nitrification	0.26 (0.92)	50.4 (16.3)	nitrification
fecal coliforms[3]	$1.9x10^5$	568	99.7	$1.9x10^5$	170	99.91
EC25 (umhos)	1108 (163)	783 (315)		1117 (241)	752 (127)	
Temp. (°C)	12.4 (1.8)	5.4 (3.2)		17.2 (3.2)	16.4 (3.7)	
pH						
DO (mg/L)	0.5 (0.4)	5.7 (2.5)		0.3 (0.6)	3.5 (1.8)	

N= 15 winter, N=24 summer

[1]average during the seasonal period (Standard Deviation);

[2] mean percent removal based on: ((inflow-outflow)/inflow) x 100 = % removed;

[3]geometric mean colony-forming units (cfu) per 100mL.

Table 17 . Summary of Fecal coliform concentrations in NERCC alternative system effluents from all years. Mean annual flows (averaged from winter and summer means, in gal/d): Peat (in-ground) = 188; Sand (in-ground) = 254; Constructed Wetlands = 211 ; Peat (modular-Irish) = 255 ; Peat (modular-MN) = 250; Textile = 244. Note that there is no regulatory standard for fecal coliform concentrations because effluents are dispersed subsurface, not into surface waters (see text). No systems were operated in 2002. In-ground peat filters converted from gravity dosing to pressure dosing in November 1997.

		SUMMER				WINTER			
SYSTEM	YEARS (not 2002)	#	<2500 cfus	<1000 cfus	<200 cfus	#	<2500 cfus	<1000 cfus	<200 cfus
Peat Filter (in-ground)	1995-2003	108	97%	90%	84%	96	92%	88%	81%
Sand Filter (in-ground)	1996-2003	133	88%	84%	74%	121	78%	66%	40%
Textile Filter (re-circ)	1999-2003	23	95%	73%	56%	15	89%	82%	13%
Peat Filters (modular) - Irish	1998-2003	29	100%	97%	90%	31	71%	61%	35%
Peat Filters (modular) -MN	1998-2003	26	80%	69%	42%	29	48%	41%	7%
Constructed Wetlands	1996-2003	116	84%	70%	45%	82	35%	20%	7%

Table 18. Summary of freezing problems, frost protection methods, and snowfall at NERCC during 8 winters of operation from 1995-2004.

Winter	Snowfall (Inches)	Peat (in-ground)	Peat (modular)	Sand (single pass)	Textile (recirculating)	Wetland	Drip (4 depths)
1995-96		No problems *Straw used*	Not constructed	Not constructed	Not constructed	No problems *Straw used*	Not constructed
1996-97	135 >12" early snow	No problems *Straw used*	Not constructed	No problems *Straw used*	Not constructed	No problems *Straw used*	No problems *Straw used*
1997-98	130 >12" early snow	No problems	Not constructed	Freezing (human error) *Ends exposed, not covered*	Not constructed	No problems *Straw used*	No problems *Tall grass no straw added*
1998-99	80 0-7" snow cover	No problems *But supply line froze*	Near freezing *Uninsulated lids*	No problems *Wood chips added*	Not constructed	No problems *Straw used*	Freezing *6" drip froze No straw Mowed grass*
1999-00	90 0-6" snow cover	No problems	No problems *Insulated lid & straw*	No problems *Wood chips from 1998*	No problems, *but… drain line froze trenches froze*	Freezing *No straw used*	Freezing *6" drip froze No straw Mowed grass*
2000-01	58 6-34" snow cover	No problems	No problems *Insulated lids*	No problems *Wood chips from1998*	No problems *Straw on shallow trenches*	No problems *6" peat added*	No problems *New hydraulic unit tall grass*
2001-02	8 6	All systems off ~12 months					
2002-03	56 0-2" snow cover	No problems *Dense grass*	No problems *Insulated lids*	No problems *Wood chips from 1998*	No problems *but.. drain line froze trenches froze*	Freezing *Started up late Nov 2002*	Not operated
2003-04 through Dec '03	32 2-6" snow cover	*Dense grass*	*Insulated lids*	*Wood chips from1998*	No problems	No problems	Not operated

Figure 1. Plan view of the NERCC Alternative Septics Demonstration/Research Facility.

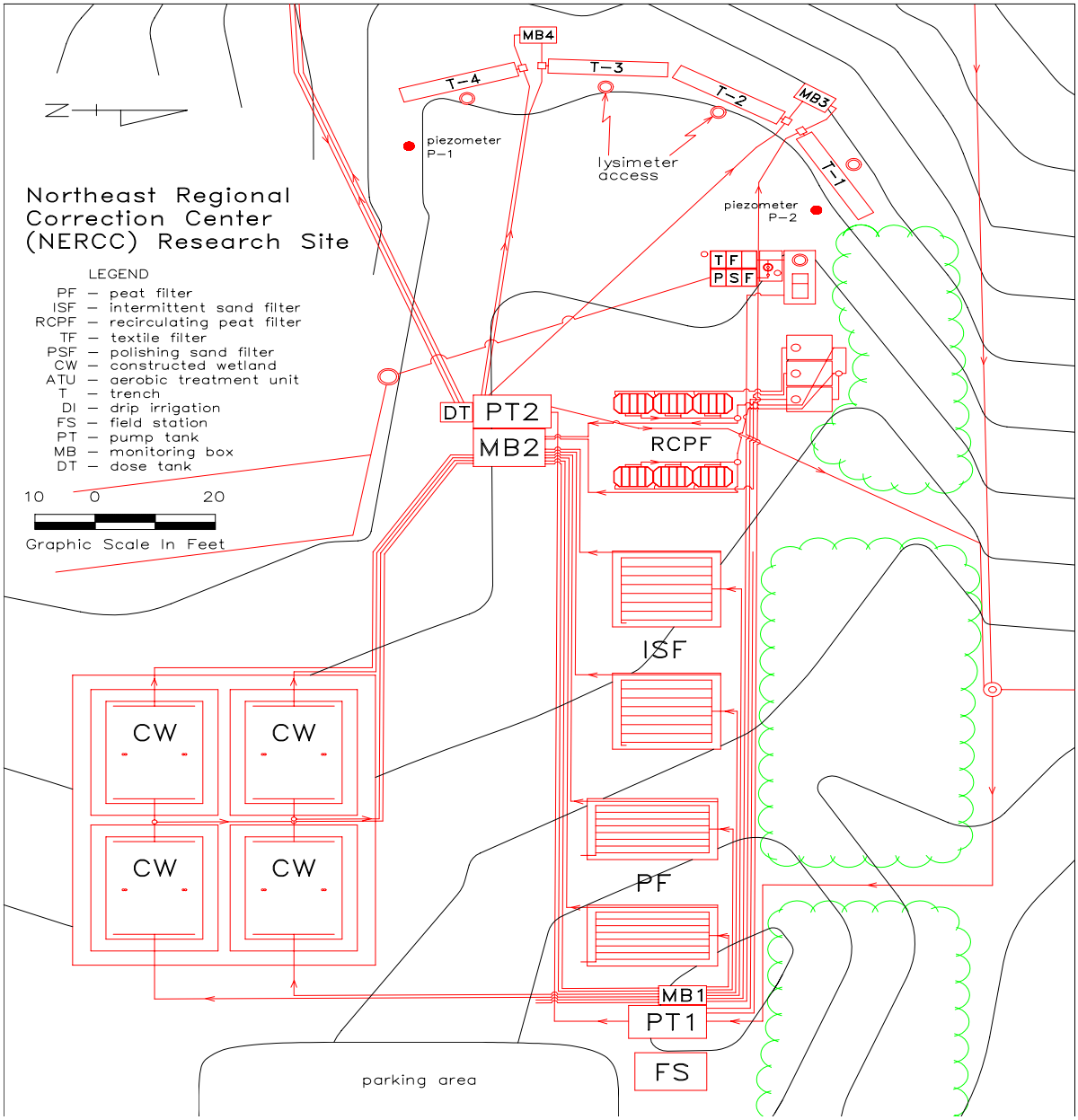


Figure 2. Schematic of the in-ground, single pass peat filters.

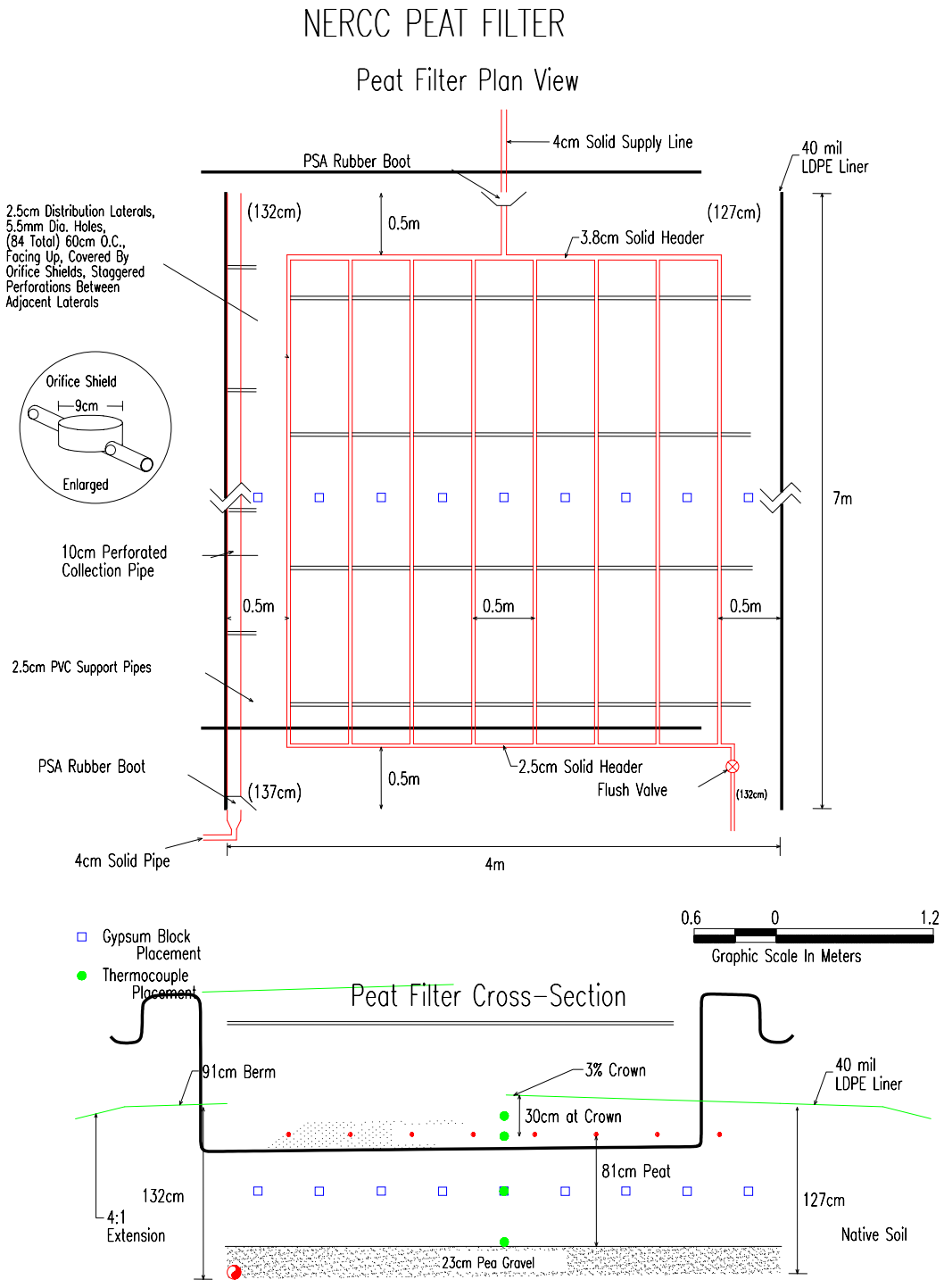


Figure 3. Schematic of the modular peat filters.

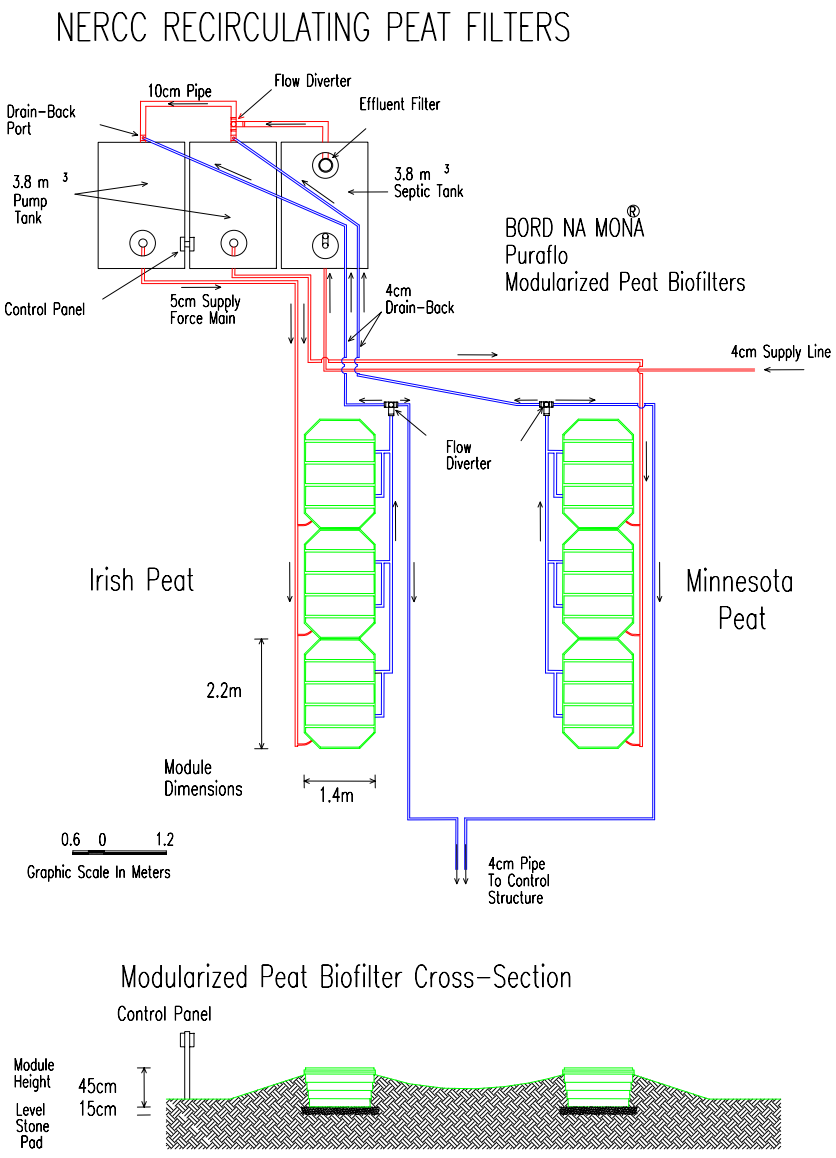


Figure 4. Schematic of the in-ground single pass sand filters.

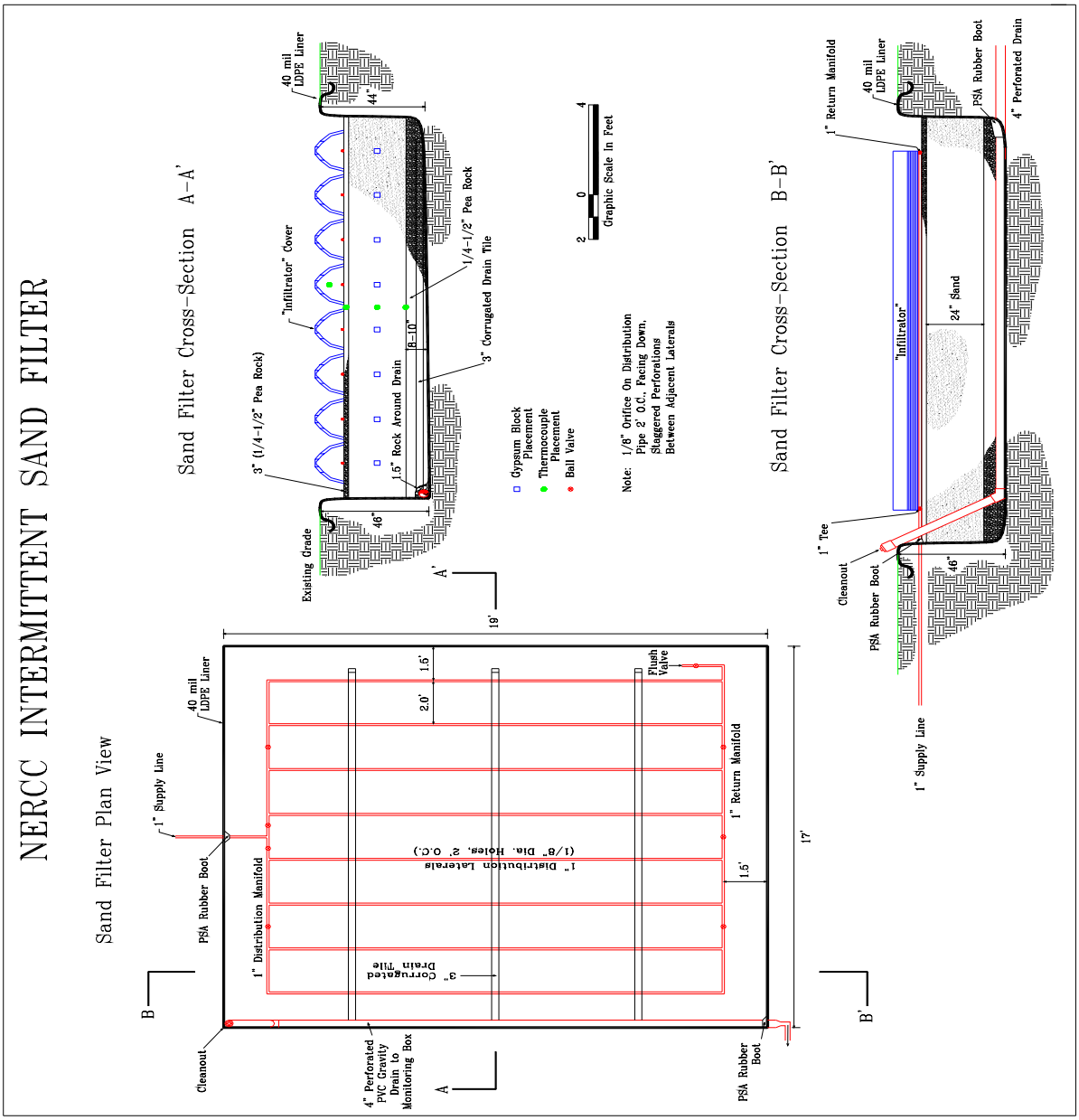


Figure 5. Schematic of the subsurface flow constructed wetlands.

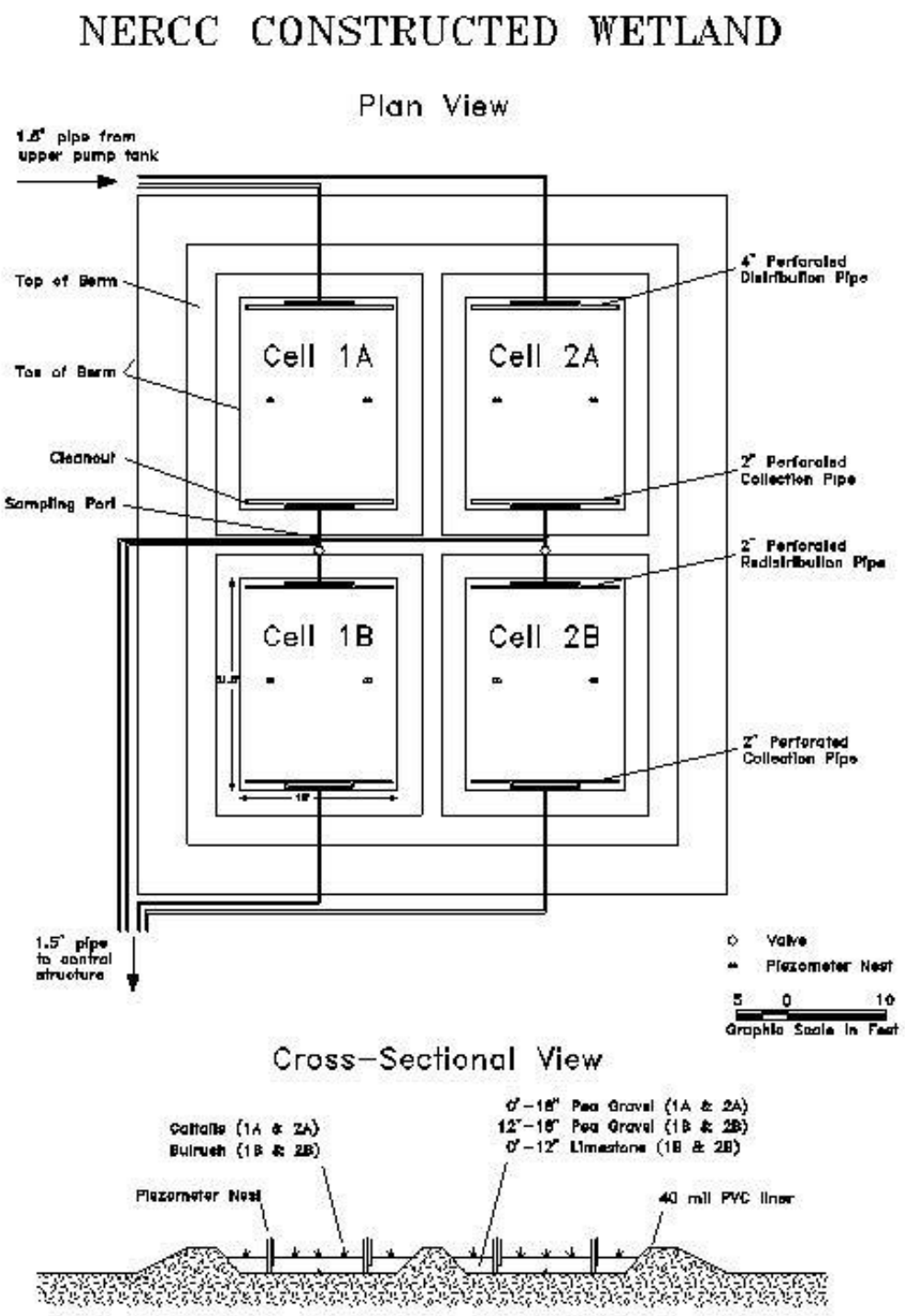


Figure 6. Schematic of the recirculating textile filter system.

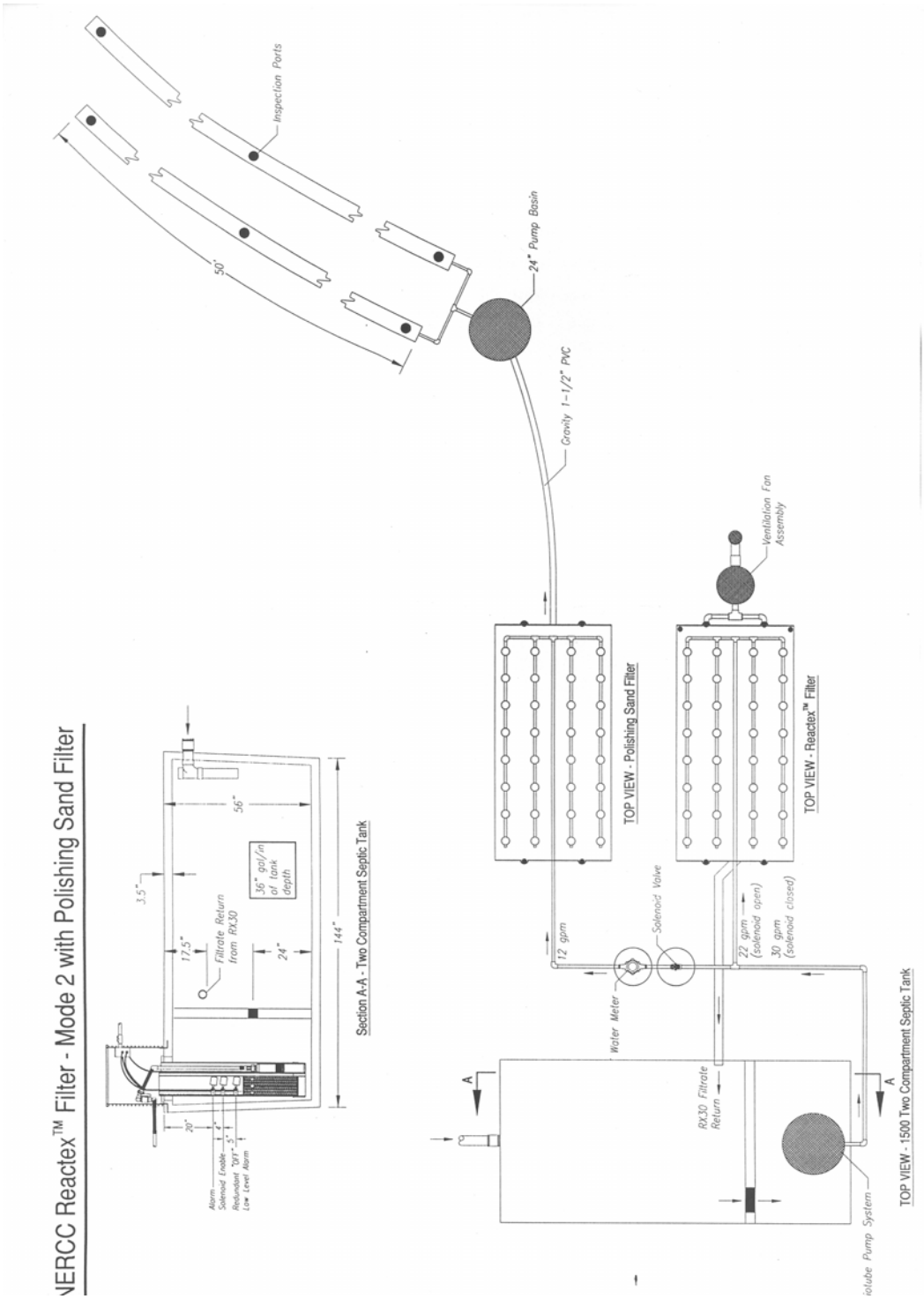


Figure 7. Image of in-ground peat filter with an exposed pressure distribution network.

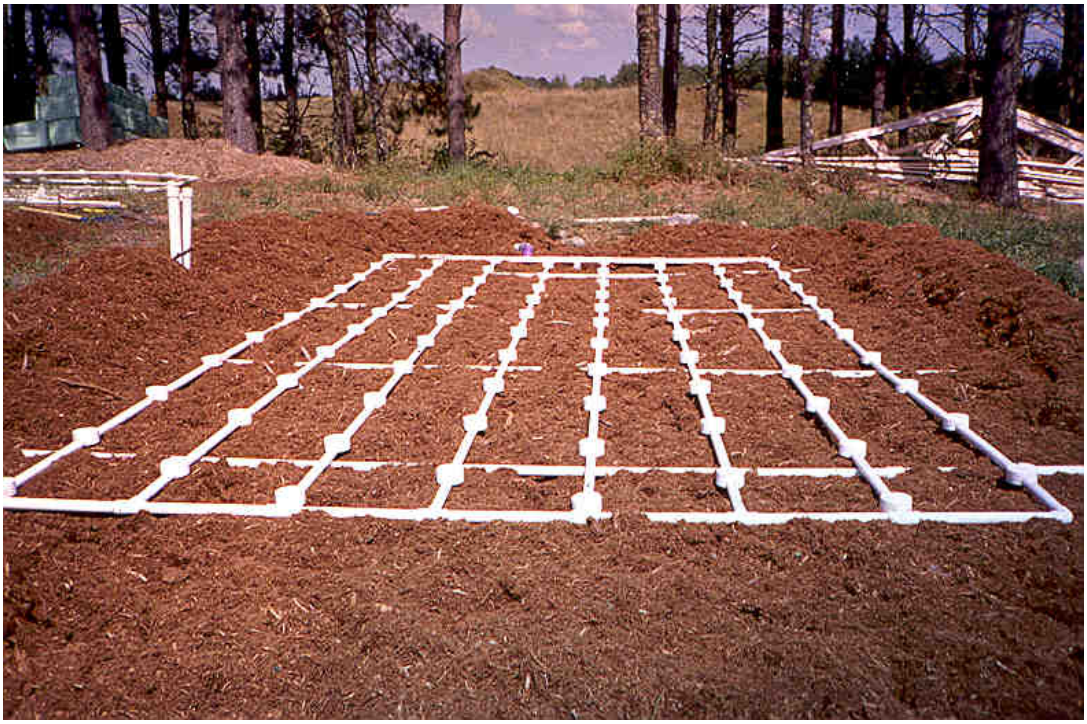


Figure 8. Image of the completed in-ground peat filters.

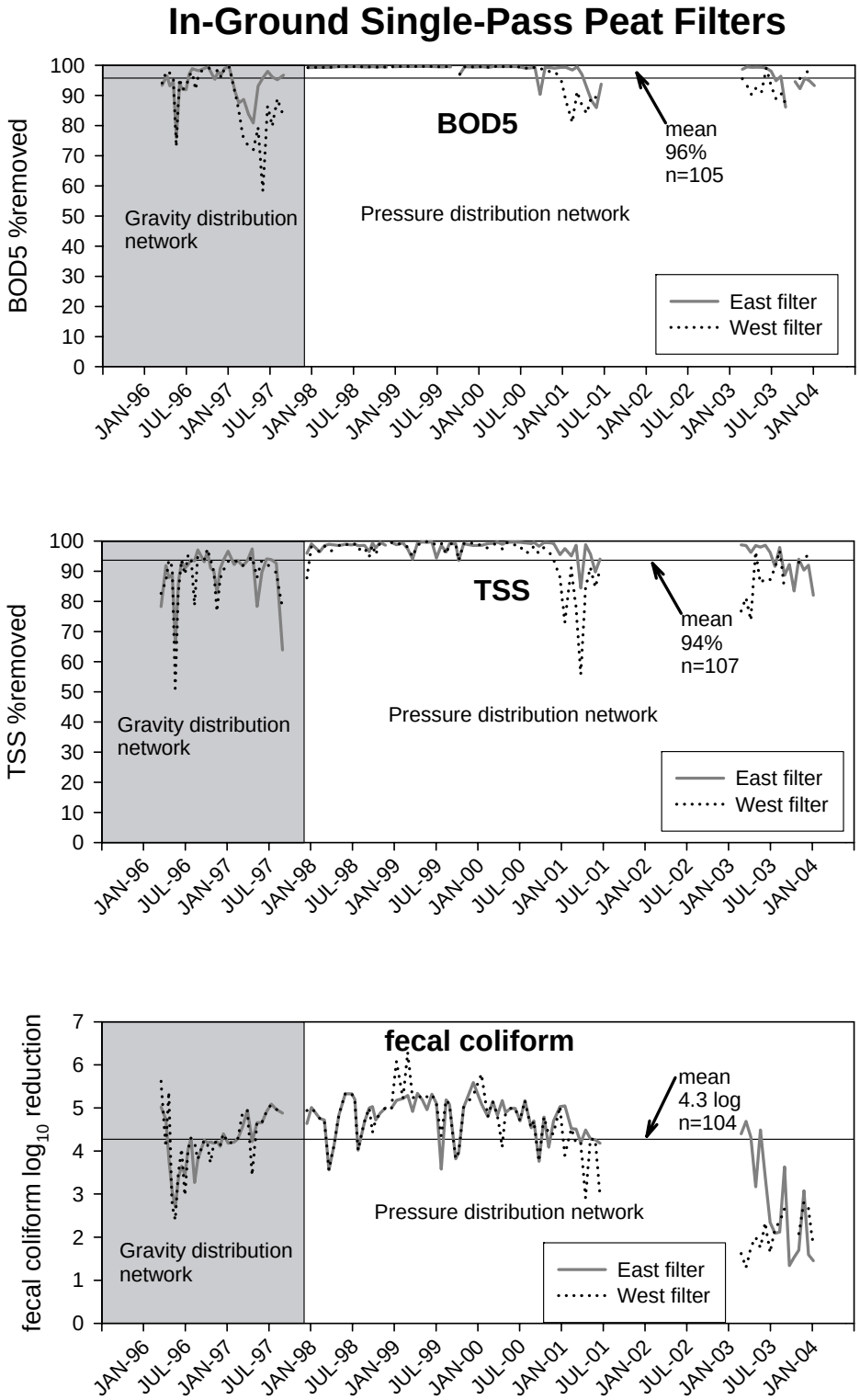
Figure 9. Image of the sand filter showing the pressure distribution network.

Figure 10. Image of the sand filter chamber covers over the distribution network.

Figure 11. Image of the finished sand filters with the wood chip layer.

Figure 12. In-ground, single pass peat filter removal efficiency, 1996-2003

A. BOD5, TSS and fecal coliform bacteria



B. TP, TN, and NH4-N

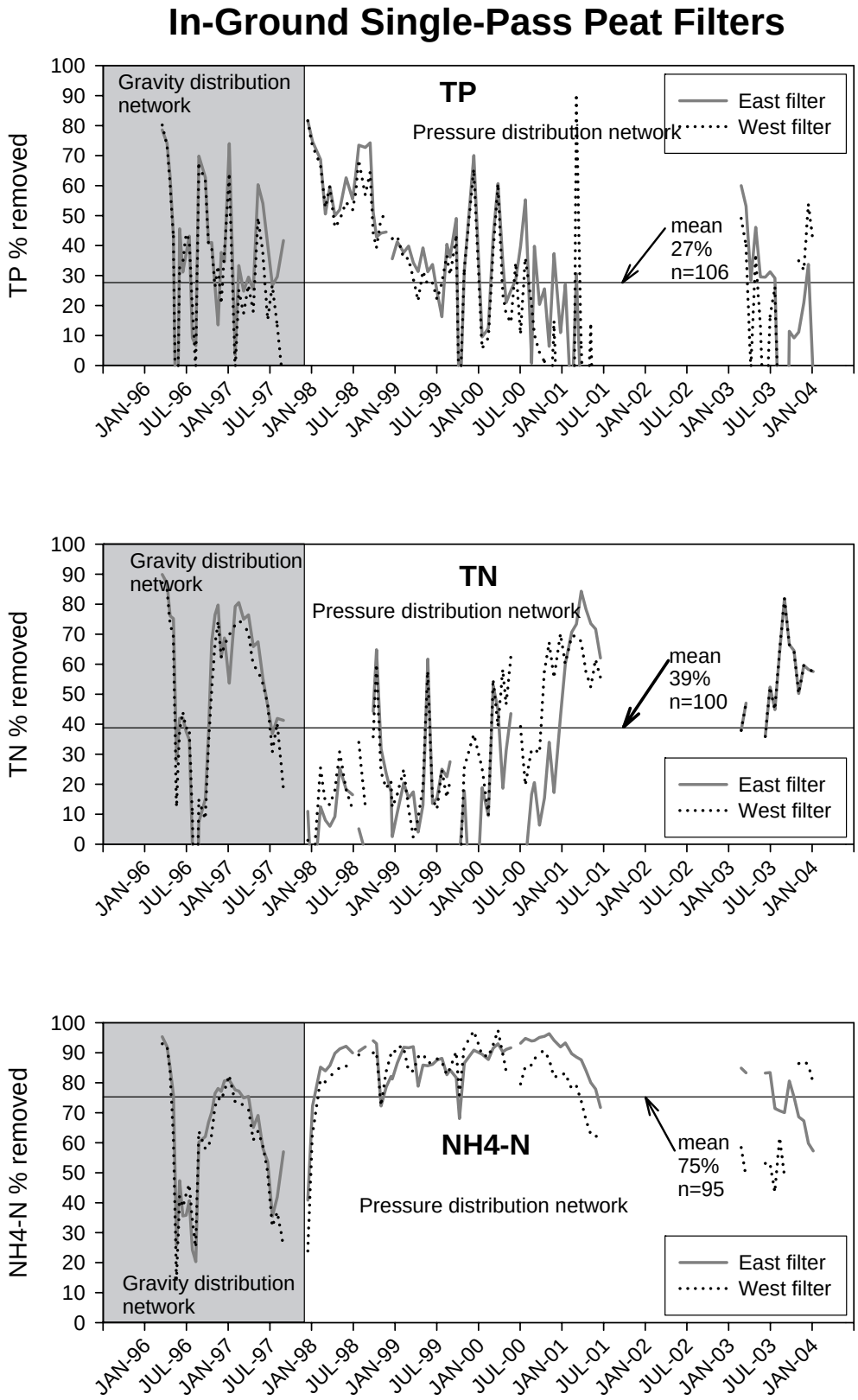
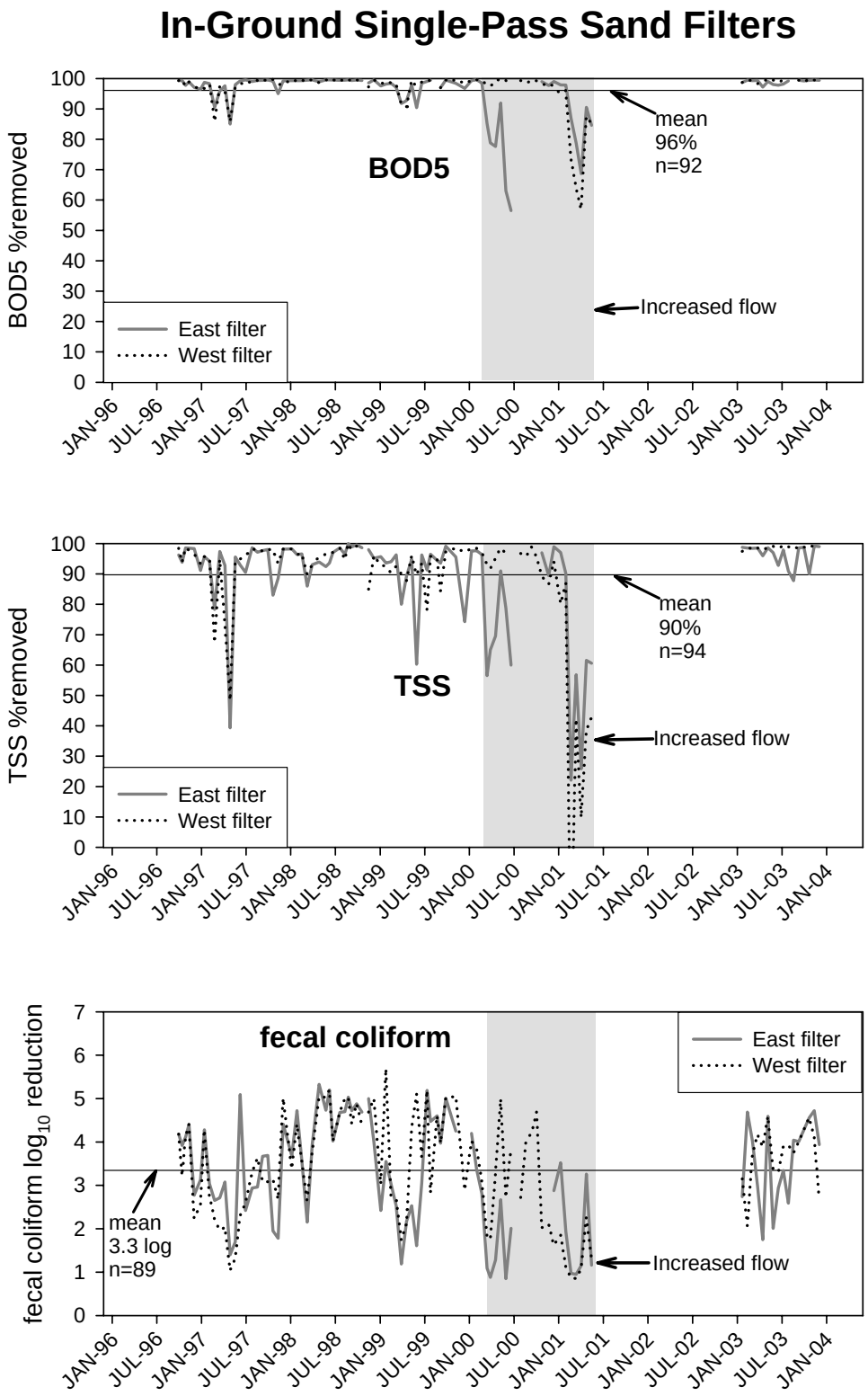


Figure 13. In-ground, single pass sand filter removal efficiency, 1996-2003

A. BOD5, TSS, and fecal coliform bacteria.



B. TP, TN, and NH4-N

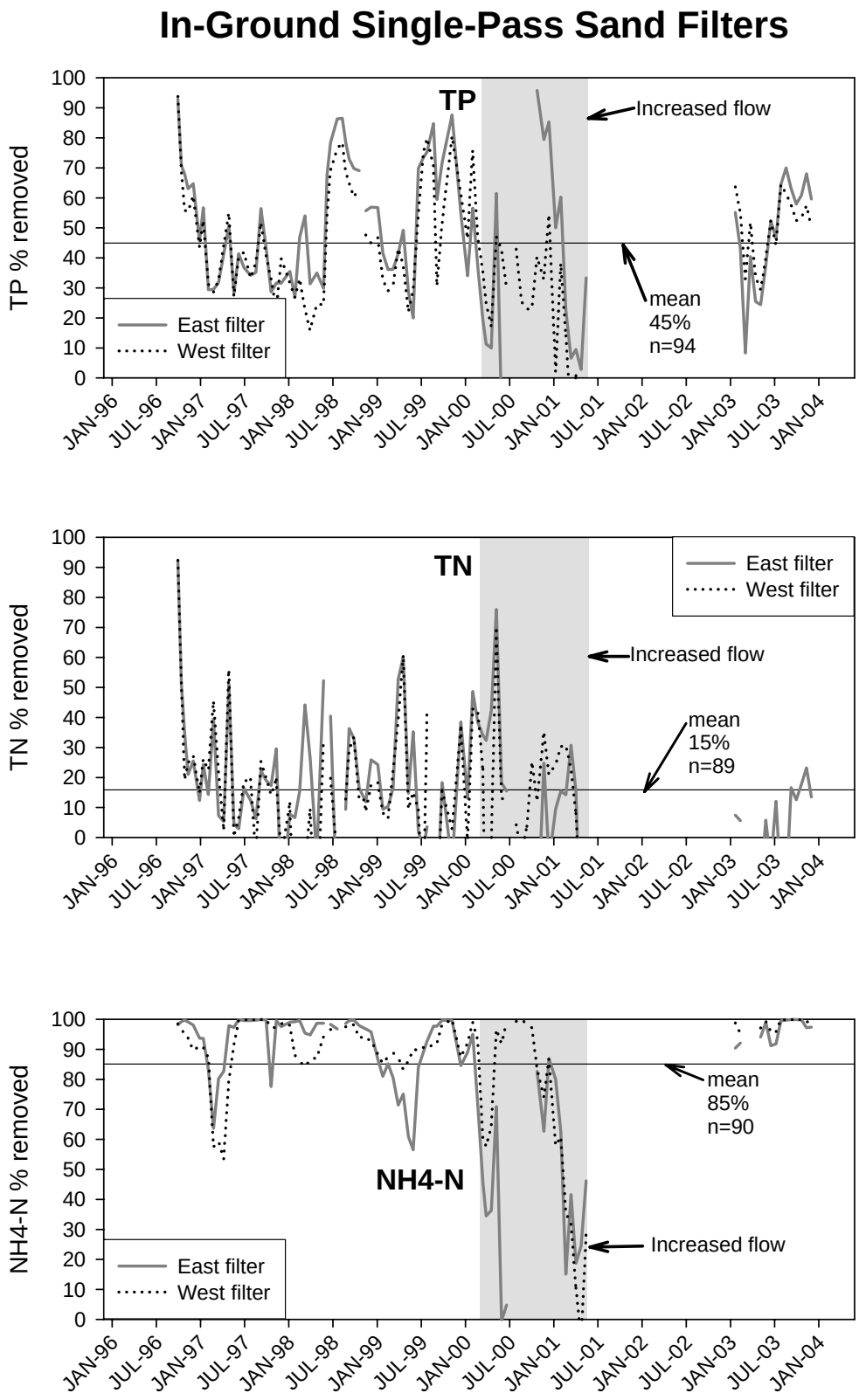
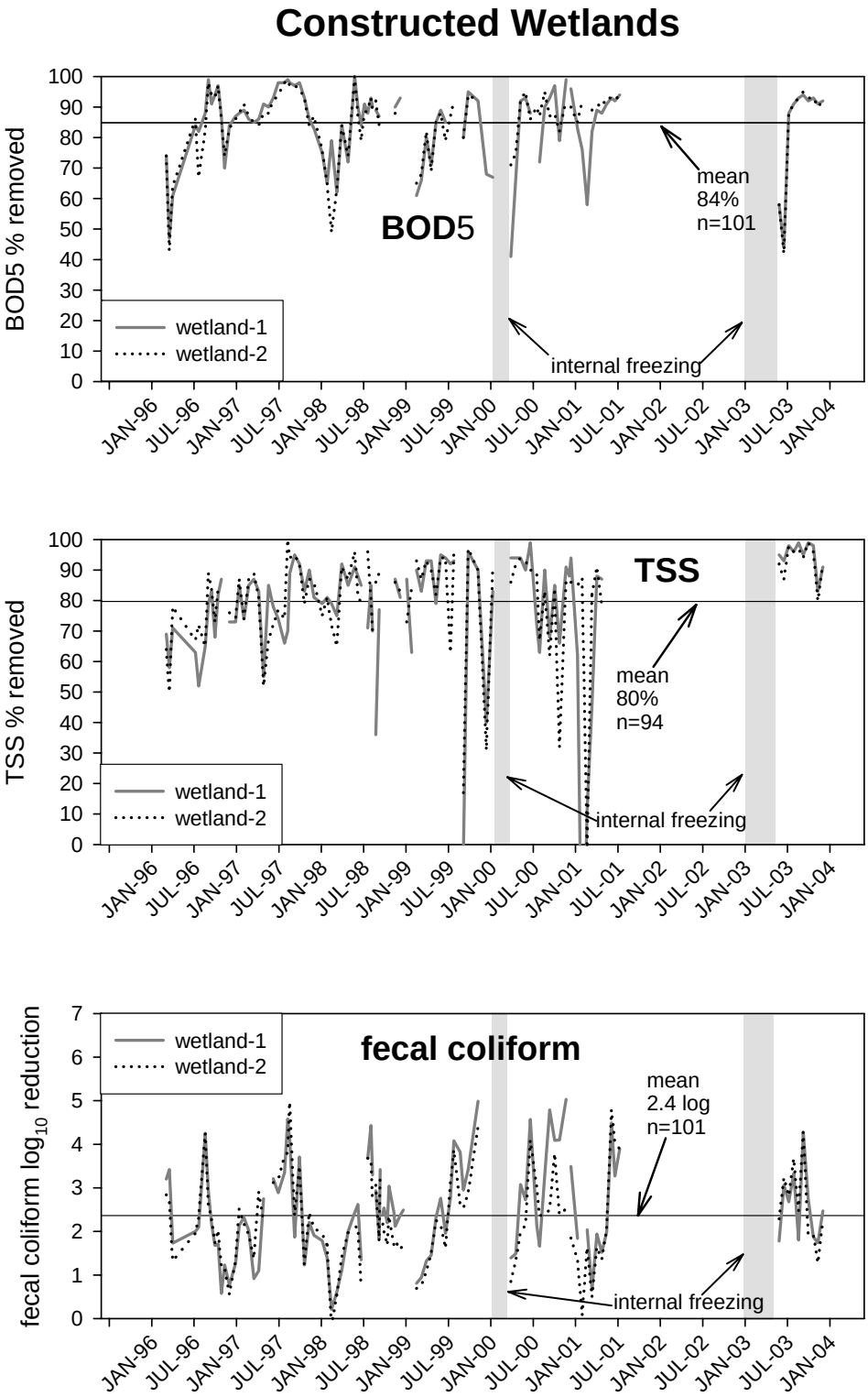
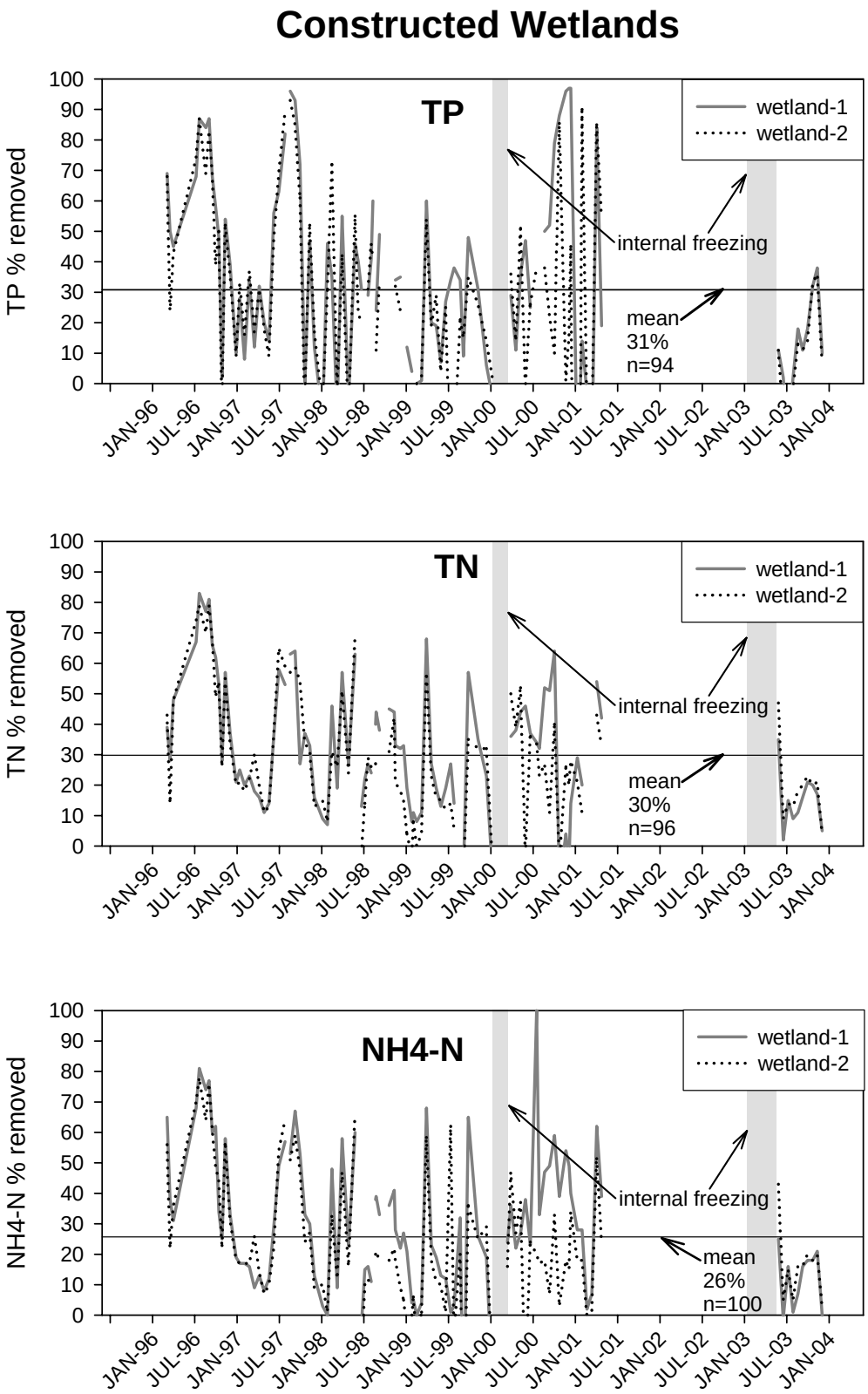


Figure 14. Subsurface flow 2-cell constructed wetland removal efficiency, 1996-2003.

A. BOD5, TSS, and fecal coliform bacteria



B. TP, TN, and NH4-N