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Performance of Alternative Treatment Systems in Northern Minnesota

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ABSTRACT

The treatment and dispersal of domestic wastewater in unsewered areas is a significant issue throughout Minnesota due to restrictive site and soil conditions. A University/multi-industry/local, state, and federal agency project was established in 1995 to design, construct, and monitor the performance of alternative treatment systems in Minnesota. Two research sites were established to evaluate alternative systems for use in areas with poor soil conditions (alternative to mounds), which reduce nitrogen to an acceptable level, and that operate effectively in the winter. The research facilities allow for a side-by-side comparison of the performance of several alternative systems and a standard trench system using the same wastewater. At the northern Minnesota location, domestic septic tank effluent (STE) was applied to submerged bed constructed wetlands, peat filters, intermittent sand filters, an aerobic treatment unit, drainfield trenches, and subsurface drip irrigation. The systems were designed to treat STE from a single family home (946 to 1287 L/d) to meet secondary treatment standards for total suspended solids (TSS), biochemical oxygen demand (BOD_5), and fecal coliform bacteria (30/25/200). Individual trenches, loaded with STE, peat filter effluent, and constructed wetland effluent, are also being monitored under the trenches at 3 depths. Removal efficiencies for the peat filters (first 18 months) were >90 percent for TSS, >90 percent for BOD_5, >99.99 percent for fecal coliform bacteria after an initial start-up period, 25 to 56 percent for TP, and 33 to 71 percent for TN. The peat filters functioned well in the winter but hydraulic failure occurred during the second spring. Removal efficiencies for the intermittent sand filters (first 12 months) were >89 percent for TSS, >96 percent for BOD_5, >99.8 percent for fecal coliform bacteria, 39 to 53 percent for TP, and 12 to 32 percent for TN. The wetlands functioned as a gravel bed during the first winter, but after this initial period, removal efficiencies were 74 to 83 percent for TSS, 86 to 95 percent for BOD_5, 96 to 99 percent for fecal coliform bacteria, 25 to 71 percent for TP, and 22 to 68 percent for TN. The wetlands are not expected to reach peak performance for another year, after the wetland vegetation has matured. The drip irrigation system placed in the soil at 4 depths did not freeze during the first winter, although start-up operational difficulties occurred in the drip control unit due to cold weather.
Keywords: Alternative treatment systems, Constructed wetlands, Peat filters, Sand filters, Subsurface drip irrigation, On-site treatment

INTRODUCTION

Approximately 27 percent of Minnesota residences depend upon individual or small community on-site sewage systems for the treatment and disposal of domestic wastewater (MPCA, 1994), and ~70 percent of the on-site systems are estimated to be out of compliance with state standards. These conventional systems are designed primarily to mineralize organic

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matter, retain solids, and prevent the contamination of surface and groundwater with pathogenic microorganisms — not to remove nutrients (Reed et al., 1995). These systems are not very effective at removing nitrogen (Harris, 1995), and in some soil conditions this is also true for phosphorus (Robertson, 1995), where the subsurface flow of nutrients from a septic system to a nearby lake can be significant. Furthermore, the discharge of wastewater into soils that do not adequately remove pathogens, nutrients, and organic matter found in human waste can degrade groundwater, and ~25 percent of Minnesota residents rely on groundwater as a potable water supply.

The design of conventional on-site wastewater treatment systems is specified in Minnesota Rules Chapter 7080 (MPCA, 1994). Many residential and commercial systems do not meet the required separation of 90 cm (3 ft) to a seasonal high water table/bedrock. Many non-conforming and hydraulically failing systems on problem sites continue to discharge to the surface/subsurface, or are required to install a holding tank as the only alternative, requiring frequent and expensive pumping. The 1994 Individual Sewage Treatment Systems (ISTS) Act was passed to promote new standards and highlight the fact that ~340,000 systems are in noncompliance with the state code.

There is a clear need, throughout Minnesota, for the application of alternative wastewater treatment technologies that are effective, yet moderately priced and simple to maintain for individual residences, clusters of residences, resorts, restaurants, and other businesses that depend upon on-site systems for wastewater treatment. This collaborative project is part of a multi-industry/local, state, and federal agency effort to design, construct, and monitor the performance of alternative wastewater treatment systems in areas with inadequate soil conditions, that operate effectively during the winter, and reduce nitrogen to an acceptable level. The effectiveness of systems is determined by their ability to remove pollutants from wastewater, including fecal coliform bacteria, BOD_5, TSS, and nutrients (N and P). The effectiveness/performance of the alternative systems is simultaneously being compared to the performance of a standard trench system receiving STE, so that alternative systems are not held at a higher standard than conventional systems.

METHODS AND MATERIALS

Research sites were established in northern Minnesota, near Duluth, Minnesota, and in southern Minnesota, near Mankato, Minnesota. In this paper, the performance data for alternative systems at the northern Minnesota research facility are presented for the first 12 to 18 months of operation. In northern Minnesota, two sites are used to evaluate alternative technologies: 1) the Northeast Regional Correction Center (NERCC), a correctional facility for 125 inmates, and 2) Grand Lake, where a long-term sewage problem has occurred due to poor soil conditions, high water table, and small lot size along a lakeshore. At NERCC, a side-by-side comparison of several replicated alternative treatment systems to a standard drainfield trench system is being performed. The community wastewater treatment system at Grand Lake includes a pressurized collection system discharging to a subsurface flow constructed wetland, and a dispersal cell located on a small mineral soil island within an extensive peatland area (McCarthy et al., 1996, 1997; Crosby et al., 1998). The southern site, located on Lake Washington near Mankato, Minnesota, uses a cluster of homes for its source of wastewater, and includes replicated subsurface flow wetlands, peat filters using horticultural Sphagnum moss peat with either gravity or pressure distribution, intermittent and re-circulating sand filters, and drainfield trenches with variable depth to a seasonal high water table (Anderson et al., 1997).

The alternative technologies at NERCC include replicated subsurface flow constructed wetlands, peat filters using horticultural Sphagnum moss peat, peat filters using a reed-sedge granulated peat (patent-pending), intermittent sand filters, drainfield trenches, and a drip irrigation (multiple depths) treatment system (Fig. 1). In October 1997, an aerobic treatment unit and a second drip irrigation system were also installed. Individual drainfield trenches are loaded with STE, peat filter effluent, or constructed wetland effluent, and are monitored below the bottom of each trench at 3 depths. Subsurface drip irrigation is being tested for year-round application using STE and is being monitored at 2 depths below the drip tubing.

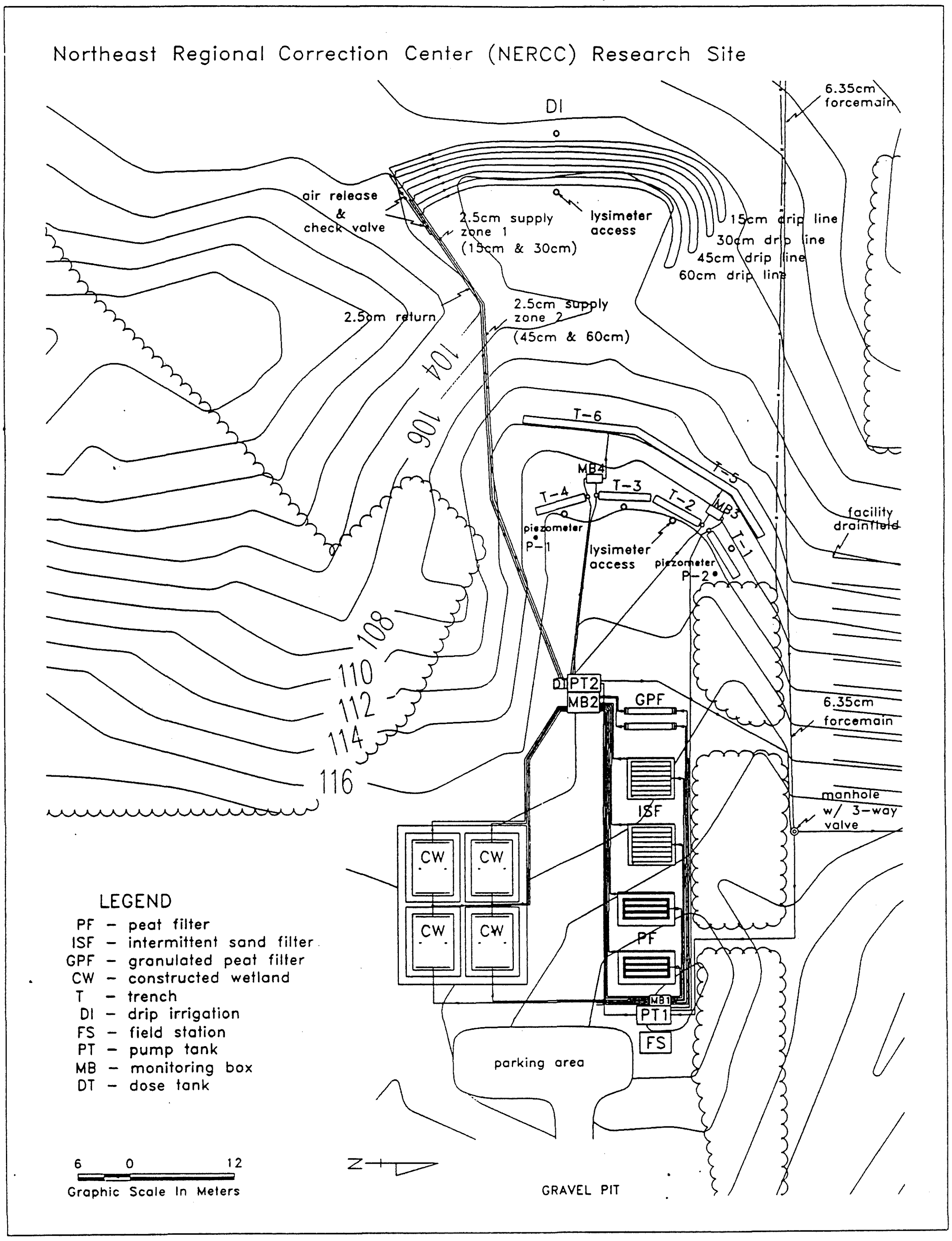

Figure 1. Schematic of the alternative wastewater treatment systems at the NERCC research facility.

Each alternative system was designed to treat STE to meet secondary treatment standards for TSS, BOD_5, and fecal coliform bacteria (30 mg/L, 25 mg/L, 200 MPN/100mL, respectively). The design flow for the peat filter, sand filter, and constructed wetland is 946 L/d (250 gal/d), and the design flow for the drip irrigation system is 1287 L/d (340 gal/d). Each alternative system (except drip irrigation) was constructed in a lined excavation using 40 mil low density polyethylene (LDPE). Submersible pumps dose each system and flows (timed dosed) can be regulated using ball valves and verified using standard city water meters at the inflow. The outflow from each system (except drip irrigation) is routed into a tipper bucket at the central monitoring station.

Sphagnum Peat Filter

The dimensions of each peat filter are 7.0 m (23 ft) L x 4.1 m (13.5 ft) W, with a total bed depth of 1.4 m (4.5 ft). The peat filters are designed to treat STE at a hydraulic loading rate of 3.28 cm/d (1.3 in/d or 0.8 gal/ft^2/d). The organic loading rate, assuming a mean BOD_5 of 200 mg/L, is 6.6 g/m^2/d (610 mg/ft^2/d). The Sphagnum moss peat was harvested from northern Minnesota, air-dried in the field, and was not screened. It was chosen to conform to material used in the State of Maine (10CMR 241, Chapter 23: Peat Disposal Systems). The peat is classified as a fibrist, with a von Post degree of decomposition of H3, unrubbed fiber content of 69 percent, rubbed fiber content of 42 percent, and organic matter content of 88 percent. The peat had a moisture content of 60 percent and a pH of 4.4.

An underdrain system, consisting of pea rock and perforated sewer pipe, collects the treated wastewater and conveys it to the central monitoring station. Peat was placed in the bed to a total depth of 80 cm (32 in), with 60 cm (24 in) placed under the distribution piping and 20 cm (8 in) above for thermal insulation. The gravity distribution system consisted of a 10 cm (4 in) distribution manifold; 4, 10 cm (4 in) perforated laterals spaced 75 cm (2.5 ft) apart; and a 10 cm (4 in) end manifold. The entire distribution network was encased in pea rock sized at 0.63 to 1.27 cm (1/4 to 1/2 in). Wastewater was originally dosed to each system 4 times/d at 227 L/dose (60 gal/dose).

Intermittent Sand Filter

The dimensions of each sand filter are 5.8 m (19 ft) L x 5.2 m (17 ft) W, with a bed depth of 1.2 m (3.8 ft). The design hydraulic loading rate is 3.15 cm/d (1.24 in/d or 0.8 gal/ft^2 /day). The organic loading rate, assuming a mean BOD_5 of 200 mg/L, is 6.3 g/m^2/d (586 mg/ft^2/d). The sand was washed to meet standard specifications per ASTM C-33 for fine aggregate (ASTM, 1992).

An underdrain system, consisting of 20 cm (8 in) of clean pea rock sized at 0.63 to 1.27 cm (1/4 to 1/2 in) and 10 cm (4 in) diameter perforated piping, collects the treated effluent to the monitoring box. Approximately 60 cm (24 in) of washed sand was placed on top of the pea rock in each sand filter. Over the sand, 5 cm (2 in) of clean pea rock sized at 0.63 to 1.27 cm (1/4 to 1/2 in) was used as a bedding material for the distribution network. The distribution network consists of a 2.5 cm (1 in) distribution manifold; 8, 2.5 cm (1 in) perforated laterals spaced 60 cm (24 in) apart; and a 2.5 cm (1 in) return manifold. Each lateral had 3.2 mm (1/8 in) diameter holes, at a spacing of 60 cm (24 in), with perforations staggered between adjacent laterals. The design network discharge rate was 57 L/min (15 gal/min), timed dosed every 4 hours, at 159 L/dose (42 gal/dose). The sand filters were covered with a chambered type of cover for access to the distribution network. The filters were covered with straw during winter to prevent freezing of the distribution network.

Constructed Wetland

The constructed wetlands are two-cell, subsurface flow systems. Additional treatment goals for the wetlands were to perform advanced wastewater treatment for nitrogen (TN <10

mg/L) during the growing season (May-October) and to improve phosphorus removal by using the best P-adsorbing, locally available substrates. The dimensions of each wetland cell are 7.01 m (23 ft) L x 5.33 m (17.5 ft) W, with a bed depth of 46 cm (1.5 ft). Clean pea rock sized at 0.63 to 0.95 cm (1/4 to 3/8 in) was used in the "first" cells and limestone crushed and screened 0.95 to 1.9 cm (3/8 to 3/4 in) was used in the "second" cells. Phosphorus removal should be enhanced by the use of limestone and by the selection of local pea gravel with the highest P-adsorption potential (Axler et al., 1996). Design hydraulic residence time is 13 days with a hydraulic loading rate of 1.27 cm/d (0.50 in/d or 0.31 gal/ft^2/d). For an average BOD_5 of 200 mg/L, the organic loading rate is 2.53 g/m^2/d (235 mg /ft^2/d). The wastewater is applied to the wetland 24 times/d, at a dose of 38 L/dose (10 gal/dose).

Subsurface Drip Irrigation

Subsurface drip technology was evaluated because of its ability to apply effluent to the soil at a low rate, while maintaining aerobic conditions in the soil. In addition, it requires minimal site disturbance relative to conventional or mound systems. If the rate of nitrogen assimilation in the root zone of the plant cover exceeds the rate of surface N-loading, then the system will also help attenuate the nitrate degradation of groundwater. Perhaps the most important issue in the use of this technology in Minnesota is its ability to function properly during the cold months, since the tubing is placed at a depth of 15 to 60 cm (6 to 24 in) in the soil.

A subsurface drip irrigation system was obtained from Wastewater Systems, Inc. STE is pumped from the drip operating unit to 2 zones of drip tubing installed at 4 depths in the soil: 15, 30, 45, and 60 cm (6, 12, 18 and 24 in). In zone 1, drip tubing was installed at depths of 15 and 30 cm (6 and 12 in), while the zone 2 tubing was placed at depths of 45 and 60 cm (18 and 24 in). Thermocouples were installed adjacent to the tubing at each depth to monitor temperature at emitters and between emitters on both the drip tubing supply and return lines. Separate 2.5 cm (1 in) forcemains for each zone were buried 1.5 m (5 ft) to prevent freezing. A common 2.5 cm (1 in) return forcemain services all zones and the required check and air release valves were installed for each zone.

The size of the soil treatment area required for the drip system was based on a design flow of 1287 L/d (340 gal/d), with the flow equally divided between zones 1 and 2. The design loading rate was 0.73 cm/d (0.29 in/d or 0.18 gal/ft^2/d) and 293 m (960 ft) of drip tubing was installed. Each emitter delivers 2.3 L/hr (0.61 gal/hr) of effluent to the soil and the dosing rate is 9 L/min (2.4 gal/min). The soil adsorption field is dosed 10 times/d at a rate of 129 L/dose (34 gal/dose). The drip controller sequentially doses each zone with effluent every 2.4 hr for 14 min so that each zone receives wastewater 5 times/d, once every 4.8 hr throughout the year.

System Monitoring

The effluent from the constructed wetlands, sand filters, and peat filters gravity drain through individual 3.8 cm (1.5 in) PVC buried pipes that are routed into a buried monitoring box. Tipper buckets with event counters are used to measure the volume of discharge from each alternative system and to allow access for sampling outflows (2 to 3 week intervals). Temperature and electrical conductivity are measured in the field with YSI probes and the temperature of the drip tubing is measured with an Omega digital thermometer. Water samples are analyzed for TSS, BOD_5, fecal coliform, dissolved and total phosphorus, total-N, dissolved-N, ammonia-N, nitrate-N, pH, and chloride. All nitrogen (total-N, dissolved-N, ammonium-N, [nitrate+nitrite]-N), pH, alkalinity, major anion, and cation analyses are performed at the Natural Resources Research Institute (NRRI) using standard methods (APHA, 1995; Owen and Axler, 1991 [revised annually]). Phosphorus, BOD_5, TSS, and fecal coliform bacteria analyses are performed by the Western Lake Superior Sanitary District (WLSSD) using standard methods (APHA, 1995).

RESULTS AND DISCUSSION

This section of the report provides a brief description of system operation and maintenance and preliminary performance evaluations (12 to 18 months) of the alternative systems. Influent wastewater characteristics of the STE used in the study were typical of residential septic tank effluents (Tchobanoglous and Schroeder, 1987) with TSS ~30 to 40 mg/L (somewhat low), BOD_5 ~200 to 300 mg/L, TP ~11 mg/L, TN ~70 to 85 mg/L, NH4-N ~60 to 80 mg/L, NO3-N <0.1 mg/L, and fecal coliforms ~10^5 to 10^6 MPN/100mL (Table 1).

Table 1. Water quality characteristics of STE used in the study and performance of the peat filter during the first 18 months of operation.

NERCC SPHAGNUM PEAT FILTER												
	INFLOW				OUTFLOW				% REMOVAL			
PERIOD	1† 2/96-5/96	2 6/96-10/96	3 11/96-3/97	4 5/97-7/97	1† 2/96-5/96	2 6/96-10/96	3 11/96-3/97	4 5/97-7/97	1† 2/96-5/96	2 6/96-10/96	3 11/96-3/97	4 5/97-7/97
n	7	10	10	3	7	10	10	3	7	10	10	3
Q (gpd)	183	140	203	78	183	140	194	94				
TSS (mg/L)	34 (6.0)	41 (5.4)	39 (6.8)	32.5 (5.5)	4.9 (2.5)	3.4 (1.9)	2.9 (0.9)	2.6 (0.9)	86	92	92	92
BOD5 (mg/L)	244 (109)	202 (111)	237 (47)	212 (36.2)	12.7 (7.0)	4.8 (2.6)	22.5 (20.8)	19.2 (13.8)	95	98	91	91
TP (mg/L)	11.5 (3.8)	10.3 (3.1)	11.8 (2.2)	10.7 (1.2)	5.0 (1.5)	6.2 (1.6)	7.7 (1.5)	7.6 (1.2)	56	40	33	25
TN (mg/L)	83 (29)	73 (10)	83 (6.9)	70.9 (3.7)	24 (7.7)	49 (19.0)	25.0 (7.2)	42.2 (4.1)	71	33	70	41
NH4-N (mg/L)	70 (21)	63 (10)	70 (4.8)	61.3 (6.6)	18.9 (10.2)	28.2 (6.8)	16.6 (2.2)	35.5 (3.4)	73	55	77	42
NO3-N (mg/L)	<0.1	<0.1	<0.1	<0.1	1.3 (0.7)	19.6 (17.4)	5.2 (8.2)	0.6 (1.2)	N/A	N/A	N/A	N/A
fecals (/100mL)	$3263x10^4$ ($3324x10^4$)	$7.6x10^4$ ($2.2x10^4$)	$18.9x10^4$ ($15.3x10^4$)	$50.0x10^4$ ($9.8x10^4$)	$190x10^1$ ($370x10^1$)	$0.8x10^1$ ($0.9x10^1$)	$0.5x10^1$ ($0.1x10^1$)	$0.5x10^1$ (0)	99.994	99.99	99.997	99.999

†Denotes start-up period

Values for each period are the average value, ( ) = standard deviation

% removal based on concentration: ((inflow - outflow) / inflow) x 100 = % removed

Sphagnum Peat Filters

The peat filters were constructed in October 1995 and covered with hay to prevent freezing prior to start-up in January 1996, since the forcemain from the main facility was not completed. Sphagnum peat filters were the first systems to become fully operational at NERCC and were loaded with 530 to 757 L/d (140 to 200 gal/d) of STE during the first 15 months of operation. The peat filters were operated continuously from January 1996 to April 1997 and then from May 1997 to July 1997 at a reduced flow of ~355 L/d (94 gal/d).

Hydraulic failure in both peat filters was discovered in late March 1997, after which the wastewater loading was temporarily reduced by ~50 percent. Upon careful excavation of the filters, the reason for hydraulic failure was determined to be a combination of a biomat at the rock/peat interface and compaction of the peat within the bed. A new pressure distribution network was installed and the peat filters became operational in November 1997.

The performance of the peat filters was generally excellent for TSS, BOD_5, and fecal coliform bacteria (Table 1), with average effluent values consistently below secondary treatment standards. Effluent TSS values have been <5 mg/L (>90 percent removal), BOD_5 has been 5 to 22 mg/L (91 to 98 percent removal), and fecal coliform levels have consistently remained near detection (~5 MPN/100mL; removal >99.99 percent) for the period February 1996-July 1997. Virtually no initial start-up period appears to be necessary. The filter also functioned well in the winter, although BOD_5 levels were higher during the winter (Periods 1 and 3) than in summer (Periods 2 and 4). These results are consistent with numerous studies conducted in both warm and cold climates (White et al., 1995; Couillard, 1994).

TP-removal steadily declined from 56 percent in Period 1 to 25 percent in Period 4, suggesting that adsorption sites and inorganic minerals (i.e., Ca, Mg, Fe, Al) in the peat have become (or are becoming) used up over time. The discharge of TP increased from 5 mg/L to 7.7 mg/L during this 18-month period. The published literature indicates that peat filters are quite variable in removing phosphorus, ranging between 10 and 80 percent removal (Viraraghaven and Rana, 1991; Brooks et al., 1984). The ability of peat filters at NERCC to remove P may be limited due to the relatively low mineral content (i.e., Ca, Fe, Al) of the particular peat used.

TN-removal varied considerably with good removal (70 percent) during winter periods, but poorer performance (33 and 41 percent removal) during the summers. The dynamics of N in the filters appears to be complex. During Period 1, there were no indications of significant nitrification of ammonium, and levels of nitrate in the outflow averaged ~1 mgN/L. The dominant N-removal mechanism appeared to be associated with the adsorption and immobilization of ammonium (73 percent removal). During summer 1996, overall TN-removal decreased dramatically, but an average of ~20 mgN/L was measured as nitrate (+ nitrite) in the effluent. Presumably, denitrification of this nitrate was limited by either the presence of oxygen, or microbial carbon limitation since the BOD_5 was reduced to ~5 mg/L during this period. N-removal greatly improved in winter 1996-1997 with an average discharge of 25 mg TN/L, ~17 mg NH4-N/L, and 5-mg NO3-N/L. The decrease in nitrate concentrations in concert with excellent NH4-removal (77 percent) suggests that nitrification and denitrification were co-occurring. The development of anoxia in the filters (allowing denitrification) is consistent with the relatively long hydraulic retention time of the filters (~10 days), which was estimated from outflow rates during diagnostic shutdowns. N-removal declined from Period 3 to Period 4 despite a lower loading rate following hydraulic failure, with an associated decline in effluent nitrate levels.

Intermittent Sand Filter

The intermittent sand filters were completed in October 1996 and were covered with hay in November 1996 to protect the distribution network from freezing. A plastic tarp was laid over the chamber covers so the hay could be easily be removed in the spring. In April 1997, the sand filters experienced temporary ponding during a very rapid period of snowmelt. The ponding was likely due to the impermeable tarp placed over the covers, which ponded the snowmelt and restricted oxygen movement into the sand. To correct the problem, the distribution networks on both filters were flushed, the orifices cleaned, and the surfaces hand raked. The filters were allowed to rest for several days before the systems commenced operation, and there has been no recurrence of the problem.

Since the sand filters did not become operational until October 1996, the data set is limited to the winter/spring start-up period and summer 1997 (Table 2). Thus far, the filter has shown excellent removal of TSS, BOD_5, and fecal coliforms, in addition to providing excellent removal of ammonium via nitrification to nitrate. TSS were reduced to <4 mg/L (89 to 96 percent removal), BOD_5 to <10 mg/L (96 to 99 percent removal), and fecal coliform bacteria to <750 MPN/100 mL (99.8 percent removal). Phosphorus was reduced from 11.6 to <6.5 mgTP/L (39 to 53 percent removal) which is higher than we anticipate over the long-term, since the sand was selected for its particle size distribution, not its P-adsorption characteristics. In concert with ammonium decreasing from >65 mgN/L in the influent to <6.5 mgN/L in the effluent, corresponding nitrate values increased from <0.1 to as much as 61 mgN/L. The actual removal of TN was only 12 to 32 percent which was expected, since the sand is unlikely to adsorb or immobilize large amounts of ammonium, but rather converts it to nitrate (plus a smaller amount of nitrite). The removal rate for ammonium-N was 91 to 99 percent for this period.

Table 2. Performance of the intermittent sand filter during the first 12 months of operation.

NERCC INTERMITTENT SAND FILTER												
	INFLOW				OUTFLOW				% REMOVAL			
PERIOD	1	2	3† 10/96-5/97	4 6/97-9/97	1	2	3† 10/96-5/97	4 6/97-9/97	1	2	3† 10/96-5/97	4 6/97-9/97
n			12	6			12	6			12	6
Q (gpd)			200	222			200	222				
TSS (mg/L)			37 (6.6)	32 (9.0)			4.2 (5.5)	1.3 (0.9)			89	96
BOD5 (mg/L)			254 (79)	207 (36)			9.8 (10.7)	2.5 (1.8)			96	99
TP (mg/L)			11.6 (2.1)	10.8 (1.5)			5.5 (2.2)	6.5 (0.8)			53	39
TN (mg/L)			84 (6.7)	73 (5.8)			57.0 (20.1)	64.7 (1.6)			32	12
NH4-N (mg/L)			71.3 (5.4)	64.6 (8.1)			6.5 (8.1)	0.5 (0.7)			91	99
NO3-N (mg/L)			<0.1	<0.1			47.8 (18.9)	61.4 (6.2)			N/A	N/A
fecals (/100mL)			17.1×10^4 (12.8×10^4)	42.2×10^4 14.0×10^4			46×10^1 (78×10^1)	75×10^1 99×10^1			99.8	99.9

†Denotes start-up period
Values for each period are the average value, ( ) = standard deviation
% removal based on concentration: ((inflow - outflow) / inflow) x 100 = % removed

Constructed Wetlands

The wetlands were constructed in October 1995 and were covered with straw to prevent freezing during the first two winters. They began receiving STE intermittently beginning January 1996. In May 1996, the water level in the wetlands was dropped 25 cm (10 in) and flooded with pond water to dilute the strength of the STE. The beds were planted with locally available cattails (Typha latifolia and Typha angustifolia) in the "first" cells, and greenhouse-raised softstem bulrushes (Scirpus taebermontani) in the "second" cells. Cattails were planted where the wastewater strength would be highest, and bulrushes were planted where their potentially higher rates of oxygen translocation to the root zone would be advantageous to N-removal (Gersberg et al., 1984, 1986). However, there is no clear consensus as to the best plant to use in this climate and so this aspect of the design was speculative (Kadlec and Knight, 1996). The flow of STE to the wetlands was interrupted during the first two months to promote plant growth. Ornamental plants were transplanted from local sources in the summer 1996 and spring 1997 in and around the wetlands.

The performance of the wetlands is not expected to reach its ultimate potential for another year when the vegetation has matured. However, they have performed quite well to date (Table 3). Secondary treatment standards for TSS and BOD_5 were achieved for most periods, with removal efficiencies ranging from 59 to 95 percent. TSS effluent values declined to 6 mg/L after the start-up period and BOD_5 ranged from 10 to 34 mg/L. Although TSS was insensitive to temperature, the data suggest that BOD_5 may be temperature sensitive since the lowest effluent values occurred in summer when water temperatures were maximal.

Table 3. Performance of the constructed wetland system during the first 18 months of operation.

NERCC CONSTRUCTED WETLAND												
	INFLOW				OUTFLOW				% REMOVAL			
PERIOD	1† 3/96-4/96	2 7/96-10/96	3 11/96-5/97	4 6/97-9/97	1† 3/96-4/96	2 7/96-10/96	3 11/96-5/97	4 6/97-9/97	1† 3/96-4/96	2 7/96-10/96	3 11/96-5/97	4 6/97-9/97
n	3	7	10	7	3	7	10	7	3	7	10	7
Q (gpd)		186	232	225			262	146				
TSS (mg/L)	37 (1.0)	39 (4.9)	35.2 (14.0)	35.0 (10.9)	13.1 (3.8)	10.1 (3.8)	7.4 (4.1)	6.0 (3.7)	65	74	79	83
BOD5 (mg/L)	309 (21)	255 (96)	237 (47)	209 (33)	126 (50.2)	19 (12.0)	34 (8.5)	9.9 (8.4)	59	92	86	95
TP (mg/L)	15.1 (1.2)	12.0 (1.9)	11.8 (2.2)	10.9 (1.4)	7.2 (2.1)	3.4 (1.7)	8.9 (1.7)	3.5 (2.6)	52	71	25	68
TN (mg/L)	94 (2.1)	78 (7.8)	83 (6.9)	73 (5.8)	60 (12.5)	25 (11.5)	61.6 (10.4)	35 (12.3)	36	68	22	45
NH4-N (mg/L)	86 (7.4)	68 (6.9)	70 (4.5)	64 (8.0)	47.8 (10.8)	25.2 (12.6)	55 (9.8)	36 (12)	44	63	26	51
NO3-N (mg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.6	N/A	N/A	N/A	N/A
fecals (/100mL)	$6.7x10^6$ ($19x10^6$)	$19x10^4$ ($31x10^4$)	$19x10^4$ ($13x10^4$)	$42x10^4$ ($14x10^4$)	$80x10^3$ ($58x10^3$)	$6.2x10^2$ ($5.7x10^2$)	$70x10^2$ ($69x10^2$)	$4.5x10^2$ ($6.9x10^2$)	99.9	99.7	96.2	99.9

†Denotes start-up period
Values for each period are the average value, ( ) = standard deviation
% removal based on concentration: ((inflow - outflow) / inflow) x 100 = % removed

Effluent fecal coliform levels, after some root growth had occurred, ranged from 450 to 7000 MPN/100mL (removal of 96 to 99.9 percent based on "period" means). Performance clearly improved during the summers. Numerous studies have shown better performance than indicated to date (Gersberg et al., 1987, 1989; Kadlec and Knight, 1996), and so pathogen removal performance is expected to improve as the root systems become more fully developed.

TP-removal ranged from a low of 25 percent during winter 1996-1997 to a maximum of 68 to 71 percent during the 1996 and 1997 growing seasons, suggesting that vegetative assimilation was the dominant removal mechanism to date. Vegetation sampling for tissue nutrient content, biomass, and growth rate will be used to estimate the magnitude of this nutrient sink. The second cells in each wetland utilized limestone substrates to provide additional potential for P-removal via reactions with calcium. However, the near neutral pH of the STE, in concert with the large amount of organic carbon being mineralized by microbial action, may limit the potential effectiveness of this process.

TN-removal followed a similar pattern to TP with 45 to 68 percent removal in summer, and only 22 to 36 percent in winter. Ammonium comprised the majority of the inflow and outflow nitrogen and nitrate was not detected in the effluent until summer 1997. Substantial N-removal via nitrification-denitrification in the wetlands will depend upon the development of the root-rhizosphere of the cattails and bulrushes which were not yet fully mature at the end of the second growing season.

Evapotranspiration reduced summer outflows by as much as 75 percent in summer 1997. Therefore, if performance is expressed in terms of the mass of pollutants, removal efficiencies for all parameters were greatly increased during Period 4: 91 percent TSS, 98 percent BOD_5, 89 percent TP, 75 percent TN, and 99.95 percent fecal coliforms. Conversely, mass removal during heavy fall rainstorms and spring snowmelt during Period 3 declined substantially because of increased outflows. We have now installed continuous flow monitoring to better characterize this effect.

Subsurface Drip Irrigation

The drip system was installed in September 1996 and all disturbed areas were seeded and mulched. Discussion of the performance of the system is limited to its basic operation during the first winter (October 1996-March 1997) of operation. Temperature data, at 4 depths in the soil, are presented in Fig. 2. Overall, the drip system performed well, with the exception of two brief periods in November 1996-December 1996 when operational problems related to the cold caused the drip unit to shut down. The drip controller indicated that a flow variance had occurred in each zone, but temperatures at the drip tubing at all depths were above freezing. The system component most susceptible to freezing was the drip control unit and associated piping which was located in a small building. The problem was isolated in December 1997 to freezing in the supply/return lines located in, or immediately under, the drip control structure. To correct this problem, additional insulation and a second heater were installed, and both hay and snow were placed around the building. No freezing problems occurred after these changes were made, despite very cold temperatures of -36°C (-32°F) during January 1997-February 1997.

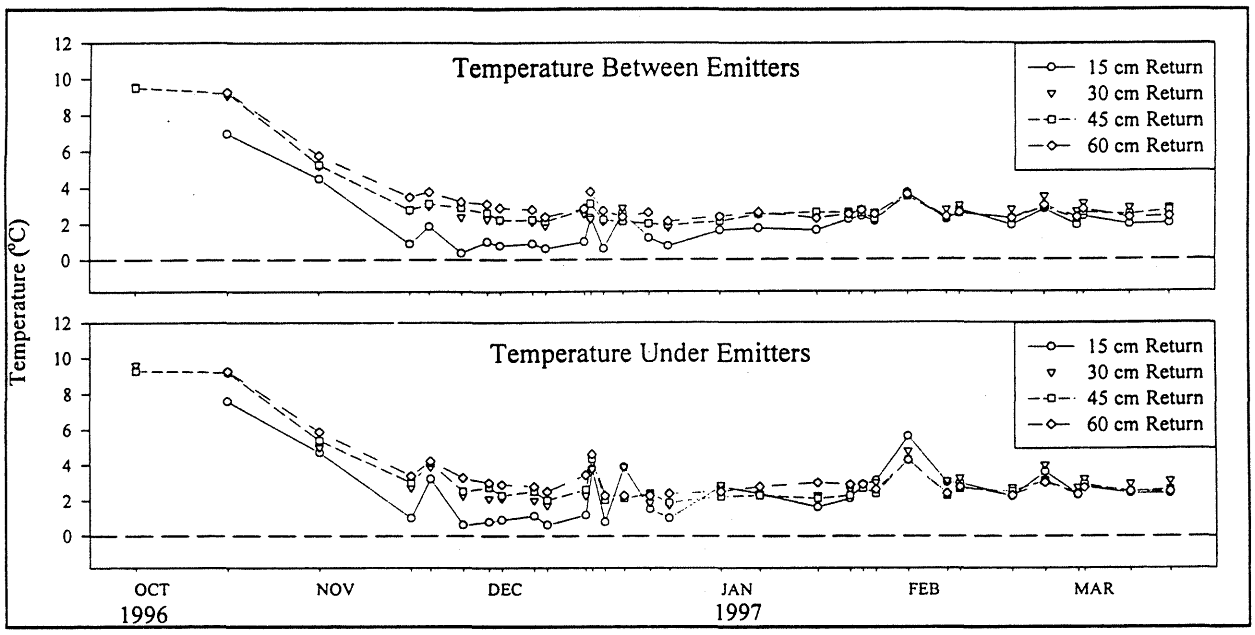

Figure 2. Temperature at the drip irrigation tubing/soil interface (between emitters and at emitters) at 4 depths in the soil.

The temperature of STE applied to the drip system was 10° to 15°C (50° to 60°F) during the winter 1996-1997. The temperature in the drip field dropped from a high of ~10°C (50°F) in October 1996 to a low of ~0.5°C (33°F) in November 1996-December 1996 when system problems occurred. Low temperatures in the drip field were due not only to cold air temperatures, but to a cold rain in late November 1996 and little snow cover. Air temperatures as low as -18° to -21°C (-1° to -6°F) were recorded at NERCC during this period. Significant snow cover did not occur until late December 1996, but then remained until mid April 1997. Figure 2 also shows the distinct increase in temperature that occurs immediately after each dose event.

Even though the 15 cm (6 in) deep drip tubing experienced the coldest temperatures, it did not freeze during the first winter. In fact, the temperature in the drip field stabilized or warmed slightly during the period December 1996-March 1997, which coincided with the accumulation of snow to a depth of 45 to 60 cm (1.5 to 2 ft) on the drip fields. In January 1997-March 1997, temperatures near the drip tubing at all 4 depths generally ranged between

2 and 3°C (35° and 38°F). Warm temperatures in the drip field can be attributed to the warm temperature of the effluent, the frequent and daily dosing of effluent, the insulating properties of the hay and blanket of snow over the drip fields, and ambient heat in the ground below the drip tubing.

SUMMARY AND CONCLUSIONS

The performance of the alternative treatment systems at NERCC was generally good. Typical removal efficiencies (and effluent concentrations) for the peat filters during the first 18 months of operation were >90 percent for TSS (<4 mg/L) after an initial start-up period, >91 percent for BOD_5 (<25 mg/L), >99.99 percent for fecal coliform bacteria (<10 MPN/100mL) after an initial start-up period, 25 to 56 percent (5 to 8 mg/L) for TP, and 33 to 71 percent (24 to 49 mg/L) for TN. The filters functioned well in the winter but hydraulic failure occurred during the second spring. Biomat development at the pea rock/peat interface and some compaction of the underlying peat likely caused the hydraulic failure as a result of wastewater ponding in the pea rock-lined trench. The gravity distribution system was replaced with a pressure distribution network in November 1997.

Typical removal efficiencies (and effluent concentrations) for the intermittent sand filters during the first 12 months of operation were >89 percent for TSS (<4 mg/L), >96 percent for BOD_5 (<10 mg/L), >99.8 percent for fecal coliform bacteria (<750 MPN/100mL), 39 to 53 percent (<6.5 mg/L) for TP, and 12 to 32 percent (<57 mg/L) for TN. The filter has also shown excellent removal of ammonium via nitrification to nitrate. Temporary ponding of effluent on the surface of the sand filters occurred during peak snowmelt in the spring 1997, caused by an impermeable cover placed over the filters for winter insulation. A permeable cover that insulates and allows oxygen to move into the filters will be used during the winter 1997-1998.

The constructed wetlands worked reasonably well (achieving secondary treatment levels) during the first 18 months, but are not expected to reach peak performance for another year, after the vegetation has fully matured. During the first winter, the wetlands functioned as a gravel bed, but after this initial period, typical removal efficiencies (and effluent concentrations) were 74 to 83 percent for TSS (6 to 10 mg/L), 86 to 95 percent for BOD_5 (10 to 34 mg/L), 96 to 99.9 percent for fecal coliform bacteria (450 to 7000 MPN/100mL), 25 to 71 percent (3 to 9 mg/L) for TP, and 22 to 68 percent (25 to 61 mg/L) for TN. No operational problems occurred with this passive system.

Surprisingly, the drip irrigation tubing placed in the soil at 4 depths did not freeze during the long, cold winter of 1996-1997, although some operational difficulties occurred within the drip unit itself. Additional insulation of the drip unit and an auxiliary heating source solved the cold weather-related problem and the system operated continuously for the rest of the winter.

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Interim Report on First Phase, July 1995 through June 1997

Development of Alternative On-Site Treatment Systems for Wastewater Treatment: A Demonstration Project for Southern Minnesota

30 June 1997

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Contents

I. Introduction

A. Background

There are an estimated half million households in Minnesota that are not connected to established septic sewer systems. Add to this the number of seasonal dwellings and cabins on lakeshores and you can see that there is a large potential for impacting the states surfaces and ground water resources. These settings are primarily dependent on individual sewage treatment systems (ISTSs) for adequate treatment and disposal of the generated wastewater. In areas with high water tables and minimal depths to bedrock, ISTSs rely heavily on the soil treatment mound system design, resulting in increased capital costs and treatment area requirements. Moreover, conventional ISTSs are relatively inefficient in removing a suite of contaminants including nitrogen. The potential pollution of surface and ground water represents an issue of large economic, environmental, and sociological significance. Contamination can lead to algal blooms during the summer that can cause fish kills, present health risks to swimmers and recreationalists, and present a general aesthetic nuisance. In addition, failing ISTSs can potentially endanger residents by increasing their susceptibility to viral and bacterial infection as well as met hemaglobinemea (blue-baby syndrome), a condition affecting infants with elevated levels of nitrate in their blood. Obviously, there is a tremendous need to investigate new products and operational opportunities in the area of on-site treatment and disposal.

Research is being conducted by the University of Minnesota in the development of alternative systems that
1) adequately treat sewage above seasonally high water tables and where inadequate soil conditions exist, and
2) reduce nitrogen to acceptable levels.

Short-term monitoring of soil hydraulics and chemical behavior leaves the researcher and the general public with a feeling of uncertainty. Previous research has taken place in this field in Wisconsin, however, the results achieved are geographically-specific and we need to evaluate improvements to the available technology. In Minnesota, this is the first opportunity to gain results specific to our area, topography, and soils. It is essential that this investigation implement a long-term monitoring strategy to determine the soil's capacity to assimilate residential wastewater. The long-term acceptant rate (LTAR) of our soils for different qualities of wastewater will not only serve as a standard for future wastewater treatment endeavors but will also ensure that our state's water resources are protected so they continue to play their invaluable recreational and aesthetic role for generations to come.

Since there are significant differences from North to South in all important aspects of how ISTSs operate this project has both southern and northern sites, the southern site near Mankato, and the northern site at the Northeast Regional Correction

Facility near Duluth. A summary of the results from the northern site are provided in a separate report.

B. Purpose and Objectives

The purpose of this project at both the northern and southern sites is to develop affordable alternative wastewater treatment systems:
1) for use in areas with inadequate soil conditions;
2) that operate effectively during the winter; and
3) that reduce nitrogen to an acceptable level.

A technical advisory team selected alternative wastewater treatment systems that were considered not only technically feasible, but likely to be effective of Minnesota's climatic and soil conditions. Feasibility includes cost of a system in comparison to a conventional system (trench/mound), applicability to small lots and difficult soil conditions, minimal maintenance, ability to operate during the winter and aesthetic acceptability. The effectiveness of alternative systems is determined by their ability to remove pollutants from wastewater, including fecal coliform bacteria (as indicators of pathogenic microorganisms), organic matter (BOD_5), solids (TSS), and nutrients (N and P). Standard trenches receiving septic tank effluent will be compared with similar trenches receiving effluent from some of the alternative pretreatment devices. In addition, an evaluation will be made on the effect of a fluctuating water table on both treatment and LTAR.

Southern Site Objectives

1. To design,.construct, and operate a collector system to correct a problem situation, representative of similar situations in Minnesota.

2. To design, construct, monitor and compare the year round performance of alternative treatment systems, with respect to a conventional trench, for treatment of single family wastewater flows. Performance will be based on the removal of fecal coliform bacteria, BOD_5, TSS, phosphorus and nitrogen.

3. To evaluate the performance of trench systems with differing separation distance above the saturated soils. Performance will be based on the removal of fecal coliform bacteria, BOD_5, TSS, phosphorus and nitrogen.

4. To evaluate the long term acceptance rate of trenches using septic tank effluent and pretreated effluent.

5. To develop a technology transfer plan to effectively communicate the results of this study to the private sector, the public (i.e. potential users), and the appropriate local and state agencies.

II. Site & Sewage Treatment System Descriptions & Designs

Two sites are used to evaluate alternative technologies at the southern location:

1) Lake Washington, where there were problems due to small lots and inadequate space to upgrade individual sewage treatment systems;

2) continued monitoring of the five systems installed in the Beauford Watershed located south of Mankato in Blue Earth County.

At Lake Washington, a side by side comparison of several replicated alternative treatment systems, and two standard drainfield trench systems are compared. In addition, a collector sewer was installed and the wastewater directed to series of gravelless drainfield trenches. This system currently serves 20 houses and cabins.

Lake Washington

Lake Washington is located 13 miles east of Mankato. The original development consisted of seasonal cabins but the area has become attractive to Mankato commuters, resulting in conversion of cabins to full-time residences. The area was originally plotted as small lots (50' x 120'), and as use of the properties has increased many lots have had no room for replacement systems. A number of the homes had parts of the system inside the dwelling. As these residents were trying to sell or upgrade their system to conform with Shore ordinances they had few options available. In fact, one of the land owners had purchased property across the road to place a trench system *(Figure 1).*

A lakeshore homeowners association was in place. As they began to collectively explore the options to upgrade their individual systems the idea for a collector system took shape. Since the residences would likely generate an adequate amount of sewage this was also considered a good location to establish the replicated alternative wastewater treatment systems.

The homeowners association entered into an agreement, with the farmer who owned the adjacent land, to purchase an area large enough to accommodate the collector systems and the research site.

Construction at the site actually occurred in four phases. The first phase was the construction of the collector septic tanks and pump stations to deliver the effluent either to the research site or to the collector trenches.

The second phase was to construct the alternative systems (peat, wetland, sand and recirculating sand filters). Two peat filters were constructed, one using pressure distribution, one using gravity distribution, two sand filters were constructed single pass, two recirculating sand filters were constructed, and two subsurface flow constructed wetlands were built. These systems are all laid out and plumbed to flow from the treatment trench by gravity to the final resting place of the wastewater. The sand filters are routed through the trenches to evaluate trench performance of treatment for long term acceptance rate and the evaluation treatment performance of the soils on the site *(Figure 2).*

The third phase was the construction of the standard treatment system. This system was designed to treat the wastewater from the homes after the research is complete. The final system was designed to accommodate wastewater flows for 20 homes. Drainfield trenches were constructed by making a level excavation 18 to 24 inches deep. Gravelless pipe was used instead of rock in the trenches *(Figure 3)*

The final step was construction of the collection sewer system *(Figure 4)*. This phase was completed, and the system became operational, in September 1996. The construction of the collector sewer was extremely complicated and individual costs were very fluid. Any retrofit system is difficult, and the project must have flexibility to deal with a variety of problems. Costs of construction and installation were estimated for both the collector sewer system and each of the alternatives developed. Individual costs of aggregates for all systems are given in Table 1.

Beauford Watershed

Results from this study are included in an interim report by C. Alexander ,1996.

1. System Designs

a. Sphagnum Peat Filter (pressure distribution)

The area of the peat bed is 320 square feet with the dimensions of 8 x 40. The total bed depth is 54 inches. The design loading rate is 250 gallons per day (gallons/day). The hydraulic loading rate is 0.8 gallons per square foot per day (gallons/sqft/day), or 1.28 inches per day (inches/day). The estimated organic loading rate assumes that the BOD_5 is 200 mg per liter or 0.42 pounds of BOD_5 per day. The peat that was used at the site was air dried, milled, and unscreened and donated by the Minnesota Sphagnum Inc. The characteristics of the peat are shown in Table 2. The peat was chosen to conform to the material used by Dr. Joan Brooks, University of Maine at Orono.

Construction of the peat filter involved excavating a hole and using plywood to line the sidewalls as a protector. Inside the plywood a 30 ml PVC plastic liner was placed with an underdrain system. The underdrain system was constructed out of four inch PVC pipe covered with pea rock. The pipe was laid with 1.8 inch per foot drop over the length. Peat was placed to a depth of 24 inches of peat under the distribution rock. A layer of drainfield rock with the pressure distribution laterals was placed on top of the peat *(Figures 7 and 8)*.

b. Sphagnum Peat Filter (gravity distribution)

The second filter was built with gravity distribution instead of pressure. Its dimensions are 20 x 20 or 400 square feet. It also was dosed with 250 gallons per day giving it a loading rate of 0.625 gallons per square foot per day or 1 inch per day. The organic loading was also 200 mg/liter or 0.42 pounds of BOD_5 per day. This system was constructed using plywood as a liner protector, 30 ml PVC liner as a sealer, and 24 inches of peat as the treatment media. The difference in this filter is that effluent is delivered in four-inch diameter perforated pipe encased in pea rock and dug into the top layer of the peat, giving a total peat depth of approximately 4 feet. The wastewater was applied approximately 4 times a day at 60 gallons per dose. Effluent was delivered using a Hydromatic shef 25 pump. The dosing mechanism was a non-demand pump float *(Figures 9 and 10).*

c. Intermittent Sand Filter

The intermittent or single-pass sand filter was installed with dimensions of 8 x 40 feet for a total area of 320 square feet. The total system depth was 54 inches. The design flow for each system was 250 gallons per day with the estimated organic loading rate of 200 mg per liter. The filter media was purchased from a sand and gravel pit. We used a specification for ASTM C-33 sand. The sieve information is found in Table 7. The filters were constructed similar to the peat filters with an excavation that was lined with 3/4 inch plywood. Inside the plywood was placed 30 ml PVC liner. In the liner was placed an underdrain system using pea rock and four-inch diameter piping that is then routed to the pretreatment dosing chamber used to does the research trenches. Two feet of ASTM C-33 sand was placed over the underdrain system, and a pressure distribution system was constructed over the top of the sand material. One of the pressure distribution systems used a typical Minnesota design of two-inch diameter pipes with 1/4 inch holes pointed down.

The second design used 12-inch dual-wall pipe cut in half as a spray basin. Effluent is sprayed into the pipe, allowing it to drip from the pipe down onto the sand filter. These sand filters were covered with soil from the site to protect them from freezing. They are dosed approximately every four hours. Each dose delivers about 60 gallons. The pump used is a Hydromatic shef 33 *(Figures 13 and 14).*

d. Constructed Wetlands

The constructed wetlands at the Lake Washington site are single cell subsurface flow systems. They were designed to treat 250 gallons per day and to meet the required discharge standards. Nothing special was done to the wetlands to improve performance. The wetlands are dosed as the sand filters are, in that they are loaded at about 60 gallons a dose, four times a day. The plants are cattails *(Typha latifolia),* obtained from Le Seuer County ditch cleaning projects, then brought to the site, cleaned, and planted into the system in the fall of 1996. About 90 percent of the cattails survived.

Construction of the wetlands involved excavation, placement of the plywood for protection with a 30 ml liner over the plywood. Pea rock was placed at a depth of about 26 inches. This was for 24 inches and a little bit of freeboard. At that point the cattails were placed. A control structure is a wier system purchased from Agridrain Corporation in Iowa. The system consists of a number of wier plates that can be placed in the structure to control the depth of water in the system *(Figures 15, 16 and 17)*.

e. Recirculating Sand Filter

The recirculating sand filter is constructed with dimension of 8' x 8' for a total area of 64 square feet. This system was dosed at a forward rate of 4 gallons per square foot per day with a recirculation ratio of 5 . The filter was dosed at approximately 20 gallons per square foot per day, or 32 inches per day. The filter media is bird grit #2, purchased from New Ulm Gravel. The particle size distribution is found in table 9.

Construction of the recirculating sand filter involved excavation, then placement of plywood for protection, and finally lining with 30 ml PVC. It was then filled with 18 inches of pea rock, topped with two feet of bird grit. A pressure distribution system was installed over the bird grit. In both recirculating systems the 12-inch dual-wall pipe was used as the distribution media. Twelve inches of drainfield rock were placed over the distribution network. These systems were left exposed to the surface *(Figures 11 and 12)*.

f. Drainfield Trenches

The research trenches were constructed in two sets of six. The first set was constructed with a three-foot separation from the bottom of the trench to mottled soil indicating periodically saturated conditions. Each of these trenches was two feet wide and five feet long. They were dosed at one end using a drop box. Four inch pipe distributes effluent within the trench and discharges into a 30 gallon sump with a pump. The sump discharges into the collector treatment trenches. The pump is used as a flow meter since it is connected to a control panel measuring the amount of flow.

Twelve inches of drainfield rock (3/4" - 2 1/2") was placed under the four-inch diameter perforated pipe with two inches of rock over the pipe.

Three trenches in each sequence of six are loaded with septic tank effluent (STE), the other three are loaded with the lightly pretreated effluent from the Intermittent Sand Filter. Each set of six trenches is loaded four times per day at a rate of 2.2 gal/day/sqft or approximately 130 gallons per day *(Figures 18, 19 and 20)*.

To monitor the occurrence of periodic zones of saturation a series of six piezometers were installed at a depth of eight feet below level surface up slope, between and down slope from the research trenches. Any return flow from these trenches is routed back to the lift station supplying the cluster drainfield trench system.

The soils at this location have been classified as Le Seuer loam and Cordova silty clay loam. Detailed soils descriptions are provided in Tables 15 and 16.

III. Methods

A. Monitoring

1. Collector Gravelless Trenches Systems

Five concrete septic tanks were installed at the Lake Washington site. Wastewater from the collector sewer serving the residences along the lakeshore is directed to this set of two 2,000 gallon, two 1,500 gallon and one 1,000 gallon tanks for distribution to the research systems or the collector drainfield system. Samples for BOD_5, nitrogen, phosphorus, TSS, fecal coliform bacteria, and chloride are taken both at the influent to this series of tanks and as the effluent passes out of the septic tanks into the lift station. Samples are currently collected at these locations twice a month.

Inspection pipes are installed at the ends of the drainfield trenches. This allows a monitoring of system performance by evaluating the length of trench being utilized to treat the effluent.

Flows to the collector system are measured through calibration of the pumps to determine delivery rates, and cycle counters and timers ***(Figure 2)***.

2. Alternative Systems

Wastewater from the lift stations is delivered to a series of six 500-gallon concrete septic tanks. From there effluent is delivered by pumps to each of the alternative systems and the research trenches by use of a flow splitter.

At the outlets of each of the alternative systems there was a sampling box established. The sampling box consisted of an excavation to the elevation of the outlets and the installation of a drop box in the outlet sewer line *(Figure 22)*. These plywood boxes are being replaced by monitoring ports consisting of 12-inch diameter (schedule 40) PVC pipe *(Figure 23)*. These facilities are much easier to sample from and to maintain during the winter.

3. Drainfield Trenches

a. Pan lysimeters

A total of 36 pan lysimeters (three beneath each section of trench) were installed. Each stainless steel lysimeter is 18 inches long x 3 inches wide x 2 inches high. The lysimeters were filled with silica beads **(?/mm)**, through a stainless steel screen and out through a stainless steel tube into a PVC receptacle. Samples are collected by applying a small suction through a 0.17 inch I.D., flexible, low density polyethylene tube connected to the stainless steel tube (Figure 21).

Each of the 12 trench sections are dosed equally from a splitter. The amount of effluent leaving the trench section is measured with a set of pumps, pump counters and timers.

Monitoring of the pan lysimeters will every two weeks for the next two years.

IV. Construction Costs, Operation and Maintenance of Alternative Systems

A. Peat Filters

The peat filters were constructed October 17 through 19, 1995, after consulting the NERC group on the construction. The excavation was dug to 50 to 55 inches from the grade. All of the peat filters were designed and developed to be drained using gravity, so they were located upgrade from the final sample location. A 30 ml PVC liner was placed inside of the 3/4 inch plywood to protect the liner. PVC liner was purchased pre-cut from Orenco Systems in Oregon. Also they can, with clear instructions on how to unfold the liner, limit the need for moving the liner around inside the system. All of the construction was done under cold weather conditions, with high temperatures around 40 F and lows around 25 F.

After the liner was placed an underdrain system was installed. The underdrain system consisted of pea rock placed at a slope on the bottom of the system and a four-inch perforated sewer pipe (schedule 3530). This sewer pipe was laid at the downslope end to collect the percolate. A section of four-inch solid (schedule 34) pipe was threaded through the liner and a boot was glued into place to obtain a watertight seal. The peat was placed over the pea rock using a backhoe in 10-12 inch lifts. The peat was leveled by hand rakes and then compacted using snowshoes. About four lifts were used, three lifts to provide the 24 inches under the system and one lift for the gravity dosing system.

After the peat was placed, the distribution system was installed. For the gravity peat filter this included a four-inch solid header pipe connected to the lift station pipe. From the header pipe four laterals were laid out. These laterals were four-inch (schedule 3530) pipe with 1/2 inch holes. Distribution trenches were dug by hand into the peat. These were checked for level and pea rock was placed under, around, and over the distribution pipe. After all four laterals were installed, they were connected to the header and leveled. Another 12 inches of peat was placed over the top of the distribution system and the entire area backfilled with soil taken from the site. A grass cover was established. The installation of the pressure peat system was the same except that four pressure-distribution laterals consisting of two-inch PVC pipe with 1/4 -inch holes is used to dose the system. The cost of the system is included in Table 4.

Operation and Maintenance

During the construction of the pressure distribution system small gravel fell into the pressure distribution lines, so before start-up these lines needed to be pressure jetted. Also because of the uncertainty, each of the pressure systems was designed with capped ends to allow the cleaning and checking for plugging of holes. Another problem occurred in the fall of 1996 when a tractor finishing the grade actually hit some of the supply-line pipe that needed to be replaced. In April of 1997 the gravity system became overloaded. The flow has been reduced and it now appears to be operating at the reduced loading rates.

B. Constructed Wetlands

Two constructed wetlands were built on November 10 and 11, 1995. They were designed to treat 250 gallons of wastewater per day. According to the wetland design information provided by Robert Kadlec, the necessary wetland area to treat this amount is approximately 928 square feet of surface area. The wetlands as installed are 16 feet by 60 feet to provide the required area *(Figure16).*

The depth of the pea rock aggregate is 24 inches. At the inlet end approximately two cubic yards of drainfield rock (washed 3/4 to 2 1/2 inch diameter) was installed as a distribution network.

The distribution system consists of a tee off the two-inch supply pipe into a four-inch perforated pipe. The collection pipes at the ends are identical and lie along the bottom. The outlet pipes are encased in the drainfield rock to protect them from suspended solids.

Two sampling points were installed in the middle of both systems. The sampling points are constructed of four-inch perforated PVC pipe glued to a four-inch straight tee. One point was placed at the bottom while the other is located 1 foot above the bottom in the pea rock. The cost of the system is provided in Table 8.

Operation and Maintenance

The wetlands were planted in August and September 1996 with locally available cattails *(Typha latifolia).* These plants were gathered during ditch cleaning operations conducted by the Le Seuer County Highway Department. A work crew from the Le Seuer County Jail planted the cattails.

During January 1997 a pump quit due to faulty wiring, causing the system outlet to freeze. Sampling and system use was suspended until late March.

The spring survival rate of the cattail plantings from the fall of 1996 were very good with approximately 90 percent survival. This is contrary to results from the NERC site, along with other research, that indicates that spring (April-May) is the best time to plant these systems.

C. Intermittent Sand Filter

The intermittent sand filters were constructed November 13 through 15, 1996. To treat 250 gpd of septic tank effluent requires approximately 320 square feet of surface area. The excavation for installation of the system is 8 feet by 40 feet. Aggregate put into the system over the liner included from top to bottom: 12 inches of pea rock on the upslope side (22 inches on the downslope side); 24 inches of washed sand (ASTM C-33); and 6 inches of drain rock (3/4 to 2 1/2 inch diameter). This roughly corresponds to 17 cubic yards (27 tons) of pea rock; 24 cubic yards (38 tons) of sand; and six cubic yards (10 tons) of drain rock *(Figure 14).*

In one of the sand filters a standard distribution system was installed, consisting of a manifold and three distribution laterals of two-inch (schedule 40) diameter PVC pipe. The distribution laterals were constructed on site with 1/4 inch diameter holes, installed at a two-foot spacing. The distribution pipe was buried by a surface layer of pea gravel (approximately two inches).

For the second intermittent sand filter the influent distribution system was aligned with the lateral holes facing upward. Covering the laterals were smooth-wall polyethylene pipe, purchased from Prinsco Manufacturing, cut in half.

A gravity drainage system was installed for both systems. The underdrains consisted of perforated four-inch (schedule 30) PVC pipe. The underdrain pipe extends through the liner using solid four-inch (schedule 30) PVC pipe which drains to the sampling ports.

The original sampling sites consisted of wooden boxes built around drop boxes where the drain pipes were emptied. In August 1996 we replaced these sampling locations with 12-inch (schedule 40) PVC pipe, with insulation installed in the top to mitigate freezing problems. The cost of the system is provided in Table 6.

Operation and Maintenance

The only significant operation problem experienced was the freeze-up of one of the sand filters, due to electrical malfunction at the main pumping station.

D. Recirculating Sand Filters

The recirculating sand filters were constructed November 20 and 21, 1995. The design for 250 gpd of wastewater requires a surface area of 64 square feet. The two units installed are 8 feet x 8 feet. Aggregate for the system from the top to bottom consists of: 12 inches of pea rock on the upslope side (14 inches on the downslope side); 24 inches of bird grit #2; and six inches of drain rock (3/4 x 2 1/2 inch diameter) *(Figure 12)*. These depths roughly correspond to: three cubic yards (four tons) of pea rock; five cubic yards (six tons) of bird grit and one cubic yard (two tons) of drainrock.

As with the intermittent sand filters, one had an influent distribution system with the PVC laterals only with holes pointed down and the other with the 18-inch diameter dual wall plastic half domes covering the laterals with the distribution pipe holes pointed upward. The system cost is provided in Table 5.

Operation and Maintenance

No additional operation and maintenance issues were encountered.

E. Drainfield Trenches

The purpose of the research trenches is to determine the effects of seasonally saturated conditions on the level of treatment and hydraulic acceptance of wastewater. The trenches were installed from June to August, 1996. Two sets of six trench sections were installed along two contour lines. Soil borings were conducted to determine the depth of soil mottling. Trench contour lines were determined on the basis of this investigation. The dimensions of each trench section is 5 feet long x 2 feet wide x 1.5 feet deep. The excavations were made using a mini excavator with a five foot wide basket. Care was taken to prevent any traffic over the trench area or on the bottoms of the trenches.

Figure 20 shows a cross section of the research trench installation. At the front end of each trench section is a drop box. At the outlet of each section a pump with running time clock was installed. The trenches were filled with 12 inches of clean washed drain rock (3/4 inch to 2 1/2 inch diameter) under the distribution pipe. An additional six inches of rock was placed around the pipe, covering it with two inches of rock. The distribution pipe was standard (schedule 30) perforated sewer pipe. The top of the drainfield rock was covered with a geotextile fabric to prevent soil from washing into the rock and infiltrating to the trench bottom, reducing the ability of the soil to accept wastewater.

Wastewater is fed to each of the trenches by gravity through the drop boxes. Each trench section is designed to accept 20 gpd of either septic tank effluent or effluent from the alternative pretreatment systems. The wastewater drains into a trench by gravity with the excess overflowing into the sump to be metered at the end of the trench section. In each sump there is a pump hooked to cycle counters and timers to measure the outflows. The pumps feed the excess effluent into a return line to the supply tanks for the cluster system for final treatment.

The research trenches were installed by the University for research purposes, so costs were not developed from these particular trenches. Trench costs were developed and are detailed for the Bakers Bay cluster system. Typically, installation of drainfield trenches for a three bedroom house costs between $3500 and $5500 depending on the need for additional septic tank capacity or lift stations.

Operation and Maintenance

The major concerns in the operation of these trenches are pump operation and calibration. From initial assessments it appears that a tripper bucket gravity return system is superior to the pump-cycle counter-timer method of measuring wastewater return flows.

B. Treatment System Performance

1. Peat Filters

The monitoring plan for the peat filters involves sampling the effluent every two weeks. Monitoring began in September, 1996.

Initial treatment performance of both the gravity and pressure peat filters was very good *(Table 10).* Unfortunately, the gravity filter experienced hydraulic failure in March, 1997. The pressure distribution filter continues to function well at the design rate. The gravity filter will be retrofitted with a pressurized system to see if it can be rejuvenated.

2. Intermittent Sand Filter

The intermittent sand filter was started in September, 1996 and the data are presented in Table 13. Thus far the intermittent sand filter has shown excellent removal of TSS, BOD_5 and fecal coliforms and removal of total nitrogen (Includes NO_3^- and NH_4^+ nitrogen).

3. Recirculating Sand Filters

The sand filters became operational in September, 1996. Performance has been excellent *(Table 12).* This system has provided the best pretreatment of all the systems evaluated. As with the other systems there is a fairly wide range of values encountered. However, most of the data corresponding to lesser amounts of treatment was recorded early in the operation of the system, and the treatment has steadily improved.

4. Constructed Wetlands

The performance of the wetlands constructed should begin to reach its ultimate potential over the next year or two. The vegetation planted in 1996 is now growing well, but is still immature. Even though the time we have monitored these systems can be considered "start up" time, the treatment has been very good. The monitoring data are presented in Table 11.

V. Education, Outreach Activities and Presentations

Numerous presentations and tours were given during the study and progress and results provided at a number of conferences and workshops. A summary of major activities is in Table 14.

All the information gained from this project has also become a significant part of the Onsite Sewage Treatment Workshop training. The experiences at the research sites and the operation and construction information and procedures has been a positive addition to the training experience.

VI. Acknowledgments—Southern Site

This project would not have been possible without the support of many individuals and government agencies. Financial support was provided through the Legislative Commission on Minnesota Resources and the Minnesota Pollution Control Agency. Extensive support through donation of supplies and equipment was provided by the Minnesota On-Site Sewage Treatment Contractors Association. The following individuals and companies provided services, supplies, and/or equipment.

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New Ulm, MN

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Sutherlin, OR

Southern Minnesota Construction
Mankato, MN

Kentucky Fried Chicken
Mankato, MN

North Star Aggregates
Mankato, MN

Globe Incorporated
Mankato, MN

Bellkato Corporation
Mankato, MN

Miller Electronics
Le Center, MN

Rhombus Technology
Detroit Lakes, MN

Burk and Associates
Minneapolis, MN

Midwest Machinery
N. Mankato, MN

Donating MOSTCA Contractors

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St. Cloud, MN

Belle Plaine Block & Precast
Belle Plaine, MN

Willmar Precast Co.
Willmar, MN

Carlson Tractor & Equipment Co.
Rosemount, MN

Tom Gysbers
Gysbers Excavating, Inc.
Cannon Falls, MN

Ron Mares
Mares Excavating
Annandale, MN

John Bruender
J. R. Bruender Construction, Inc.
Eagle Lake, MN

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Ingleside Engineering
Loretto, MN

Dianne McPherson
Nicollet County Environmental Service
St. Peter, MN

Bill Olson
Olson's Sewer Service
Forest Lake, MN

Midwest Machinery, Inc.
Burnsville, MN

Greg Senske
Ziegler **(is this a company name?)**
Bloomington, MN

Craig Carlson
St. Joseph Equipment
Shakopee, MN

Steve Boening
Boening Brothers Construction
Mapleton, MN

Ken Polifka
Ken's Excavating
Glencoe, MN

List of Figures

List of Figures

Figure 1: Lake Washington site plan and design

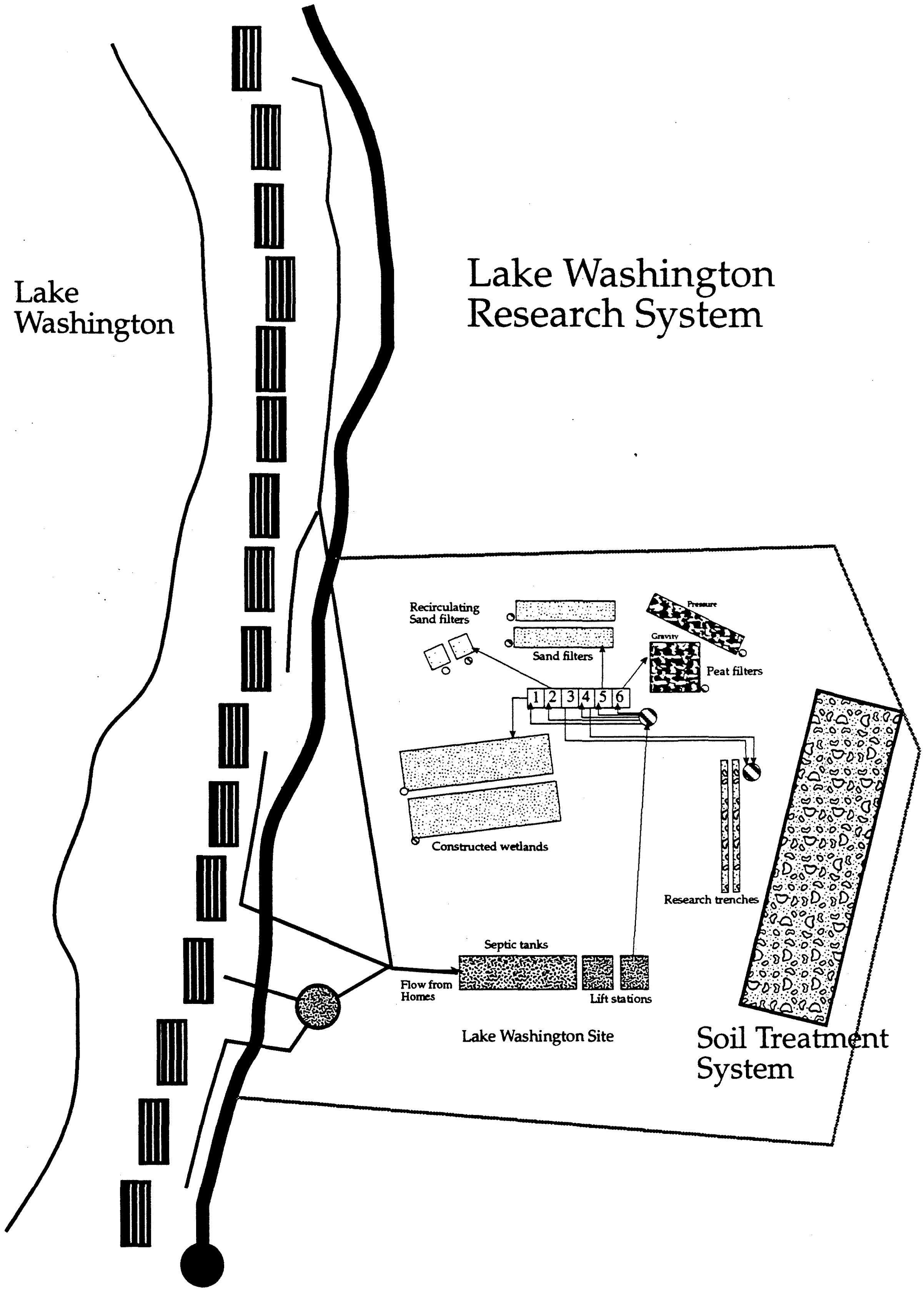


Figure 2: Lake Washington site plan and design

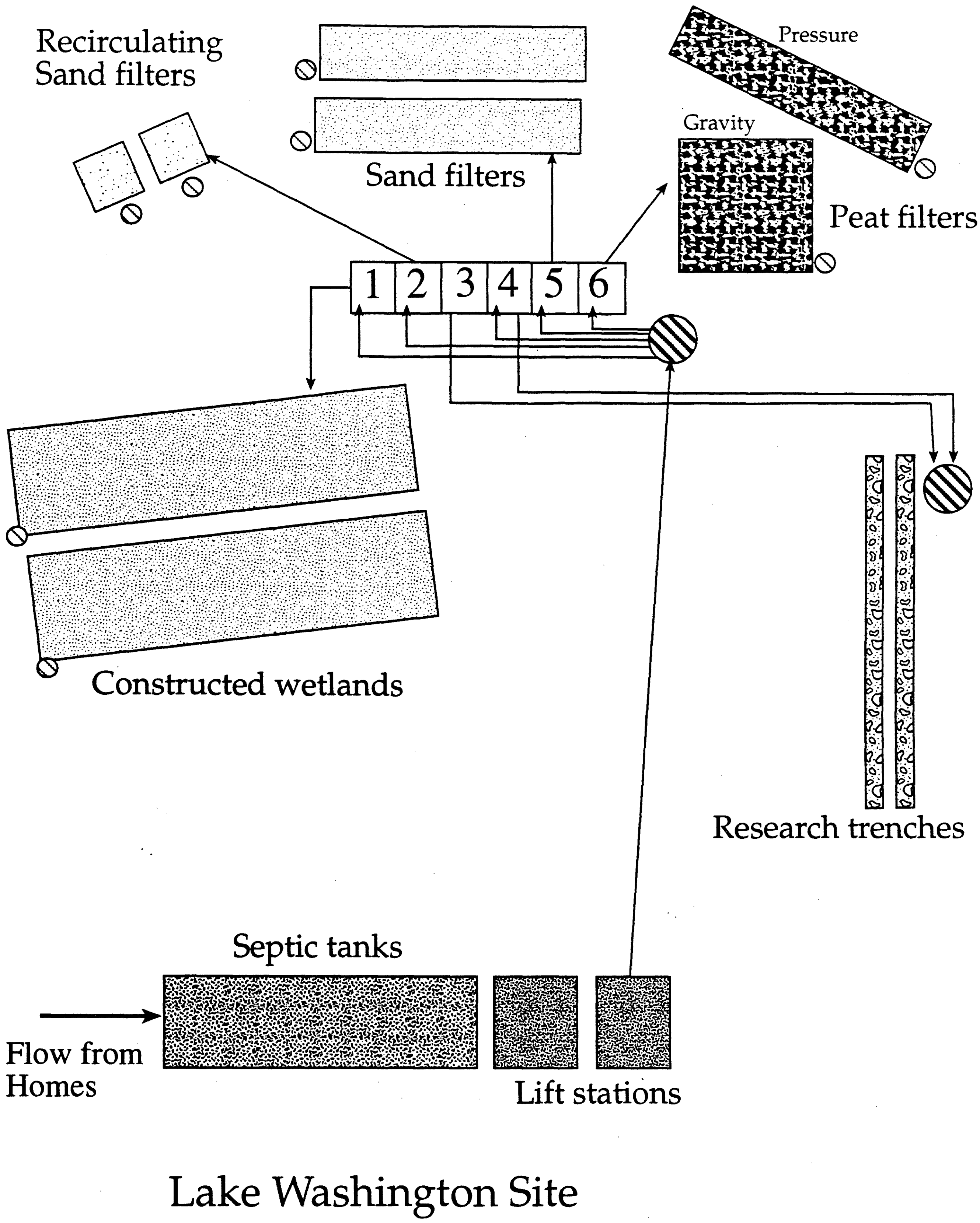


Figure 3: Lake Washington site plan schematic

Soil Treatment Area Trench Lengths

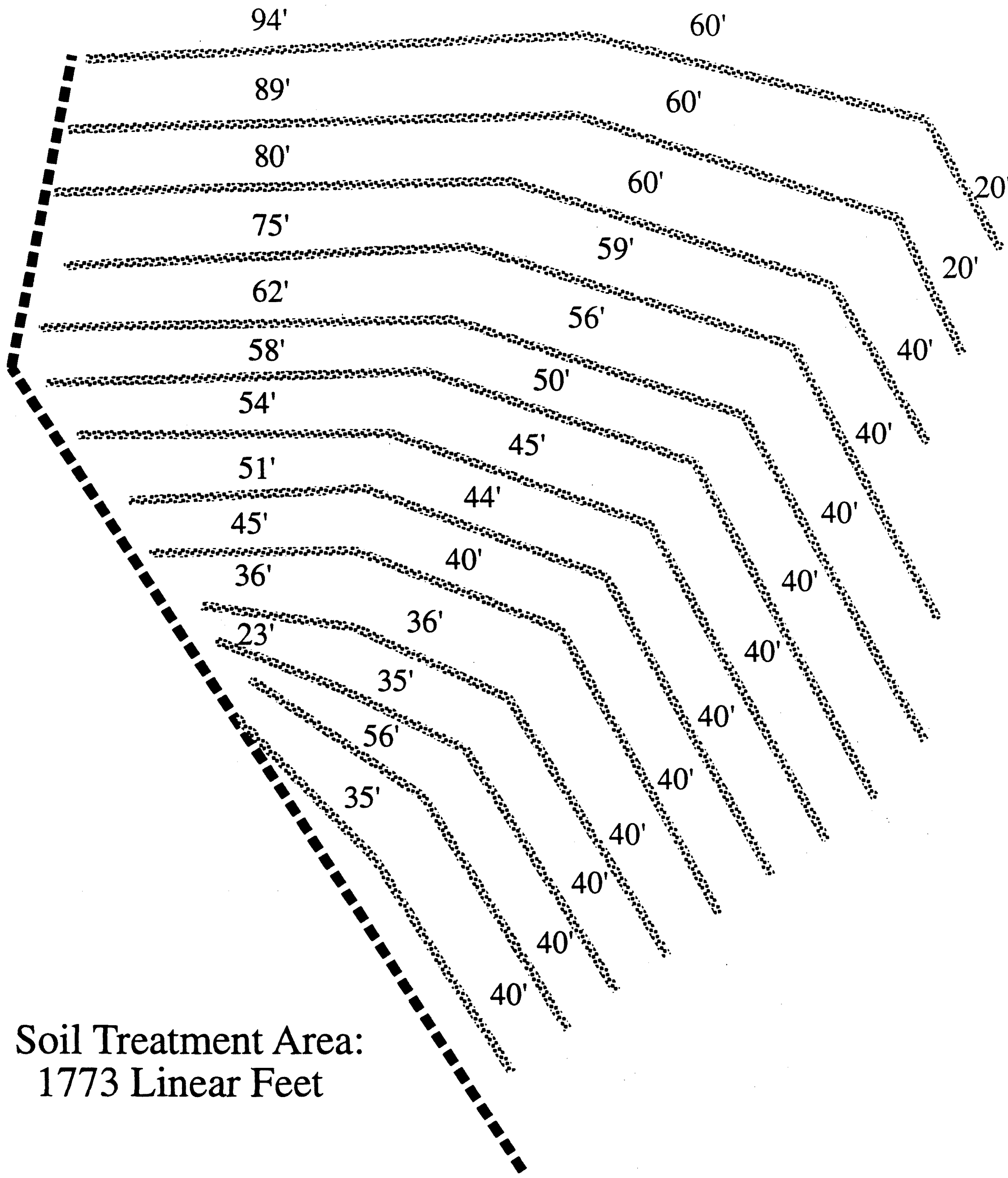
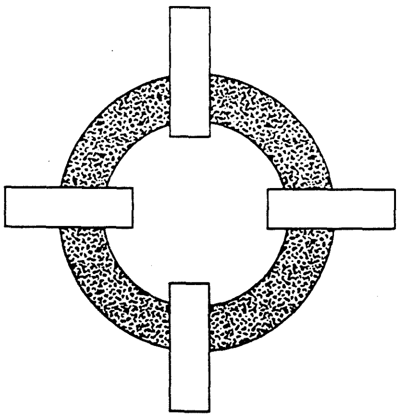
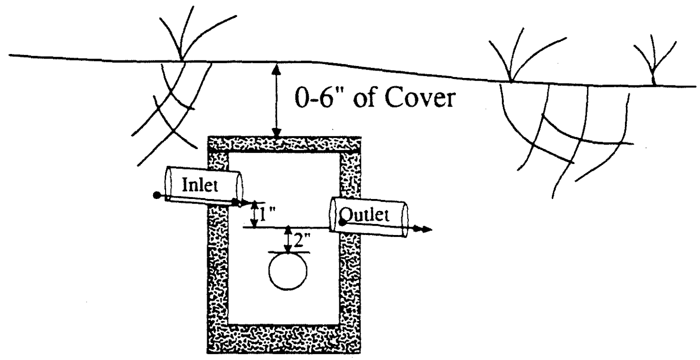
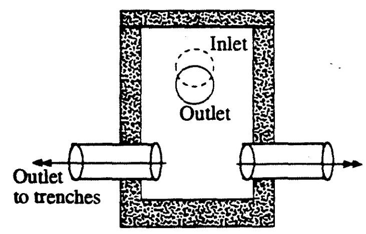


Figure 4: Lake Washington trench system







Notes:

1. All pipes should be at least 4-inch diameter.

2. Elevation of inlet supply and line to next drop box may be adjusted up or down for desired effluent level in trench.

3. Suggested trench liquid levels: (A) 2 inches above top of outlet pipe if permeable sunthetic fabric covers rock.

4. Invert of inlet must be at least one inch higher than invet of supply pipe to next drop box.

5. Trenches may outlet one side or both sides of drop box.

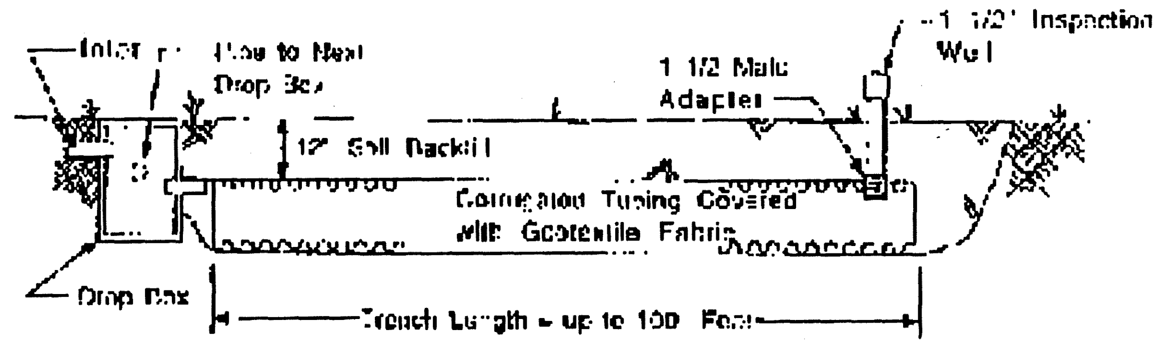
Soil Characteristics and Required Areas for Sewage Treatment

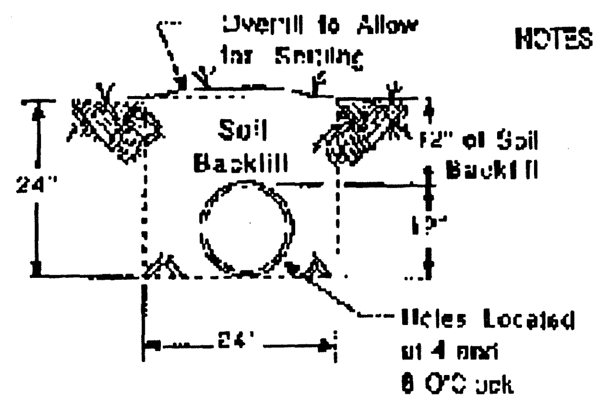
Percolation Rate in Minutes per Inch (MPI)	Soil Texture	Square feet per gallon per day	Gallons per day per square foot
Faster than 0.1 *	Coarse Sand	-----	-----
0.1 to 5	Sand	0.83	1.20
0.1 to 5	Fine Sand **	1.67	0.60
6 to 15	Sandy Loam	1.27	0.79
16 to 30	Loam	1.67	0.60
31 to 45	Silt Loam	2.00	0.50
46 to 60	Clay Loam	2.20	0.45
Slower than 60***	Clay	-----	-----

* Soil too coarse for sewage treatment. Use systems for rapidly permeable soils.
** Soil having 50% or more of fine sand plus very fine sand.
***Soil with too high a percentage of clay for installation of an inground standard system.

Figure 5: Drop box and sizing detials

GRAVELLESS TRENCH CONSTRUCTION DETAILS





NOTES. 1. Bottom of trench must be level. Top of tubing must be level

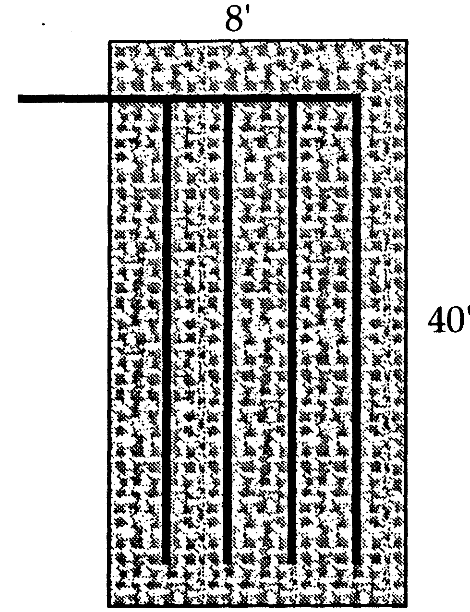
2. Scarify trench bottom and sidewalls at least 12 inches above trench bottom to expose natural soil

3. For proprietary products consult manufacturers performance criteria.

Figure 6: Graveless pipe cross section

Peat Filter

250 gpd (300 sqft: Loading rate 1 gpd/sqft)
Pressure distribution
2' Peat
Gravity drain



Peat Filter (Pressure)

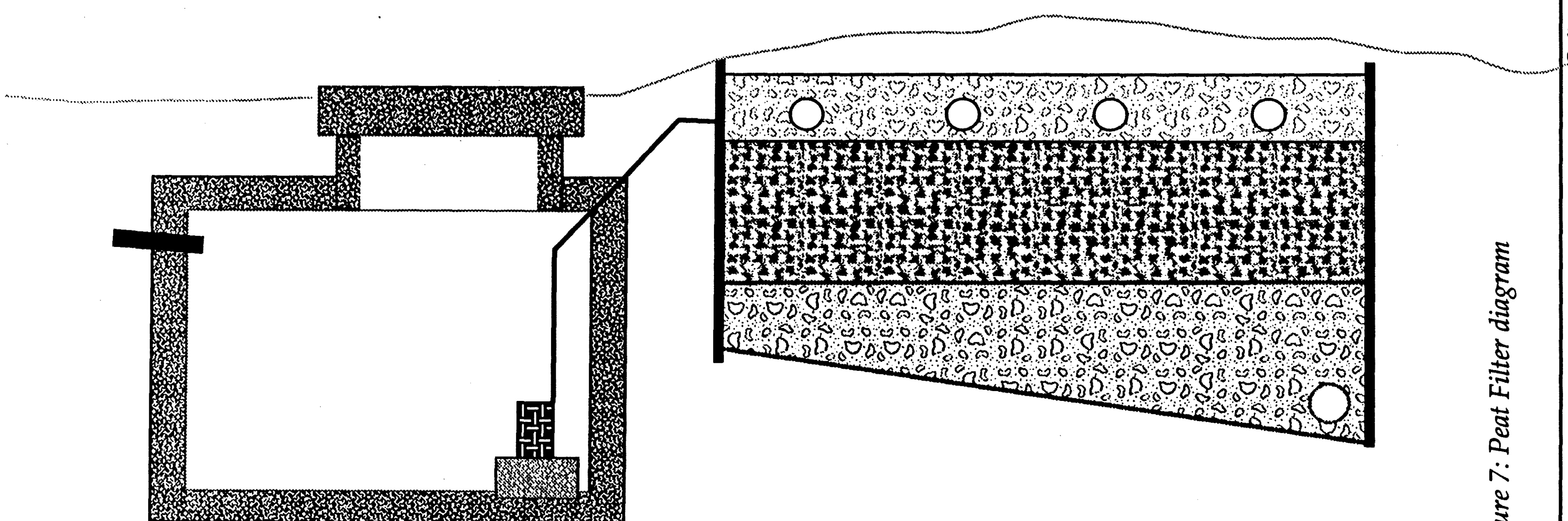


Figure 7: Peat Filter diagram

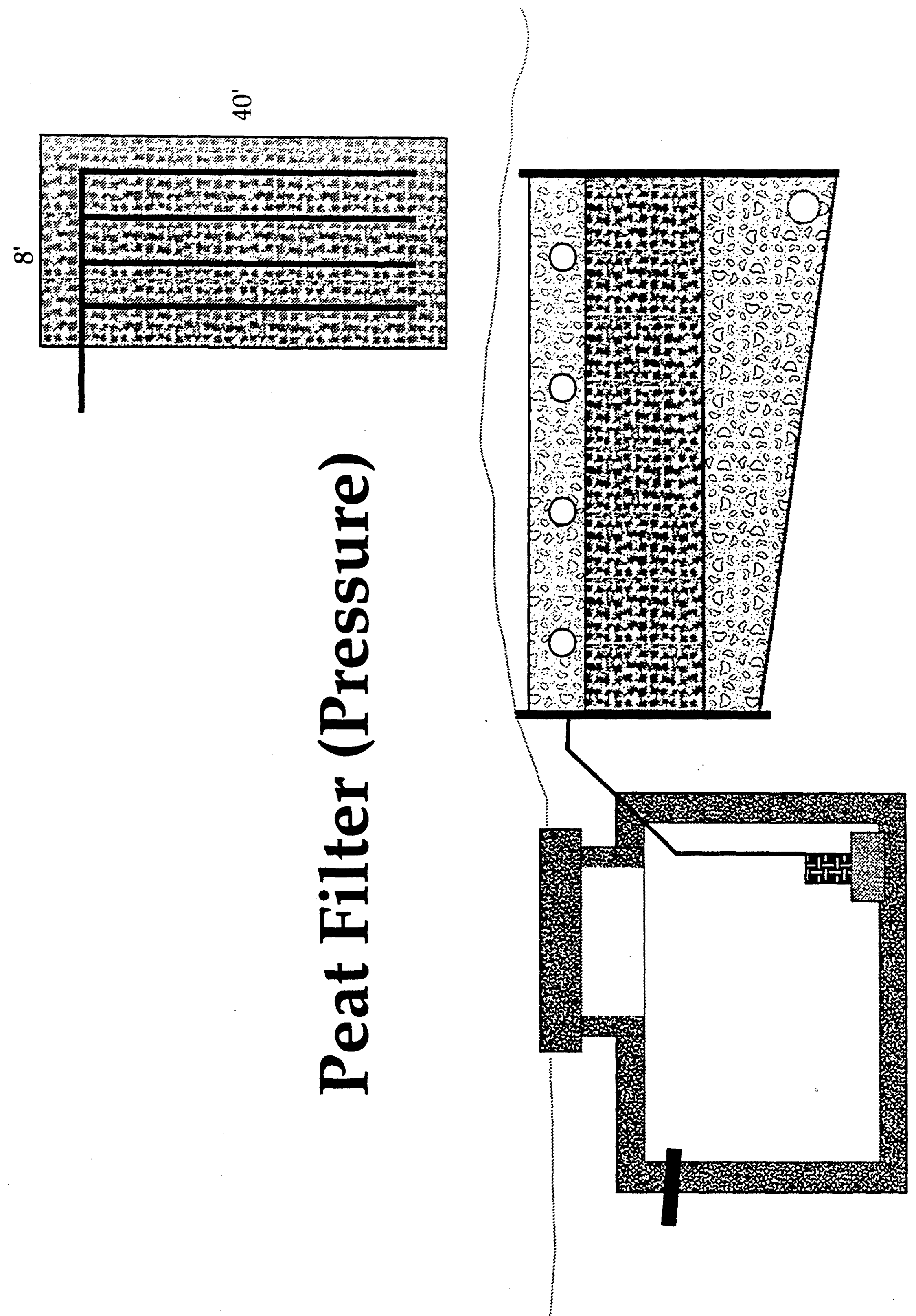
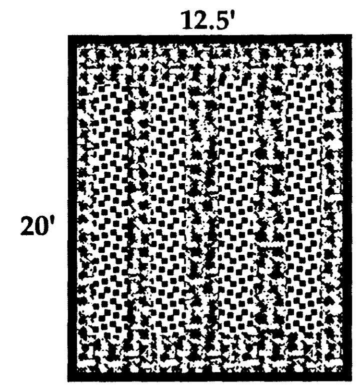


Figure 8: Peat Filter design

Peat Filter (Gravity)



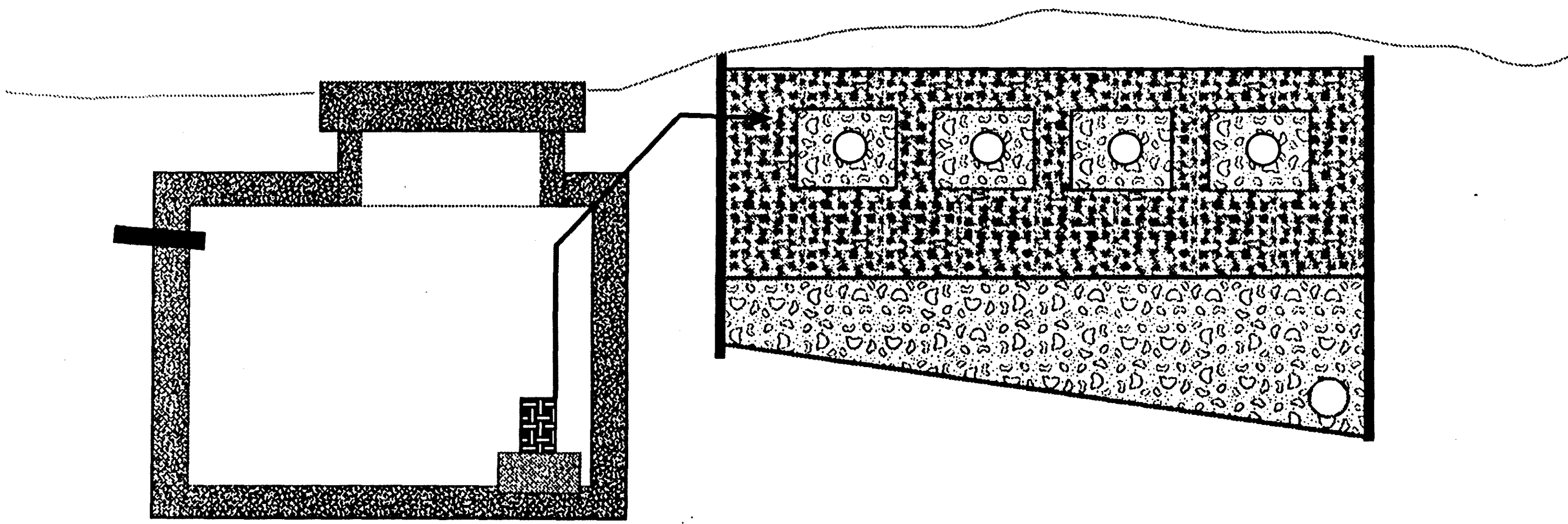
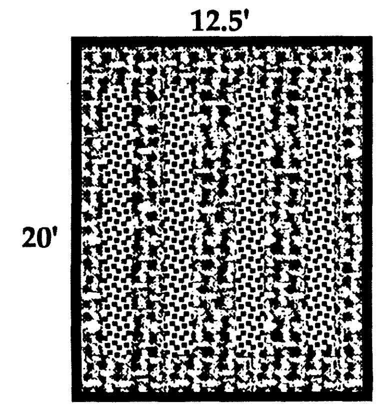


Figure 9: Peat Filter diagram

Peat Filter (Gravity)
250 gpd (300 sqft: Loading rate 1 gpd/sqft)
Pressure distribution
Gravity drain

Peat Filter (Gravity)



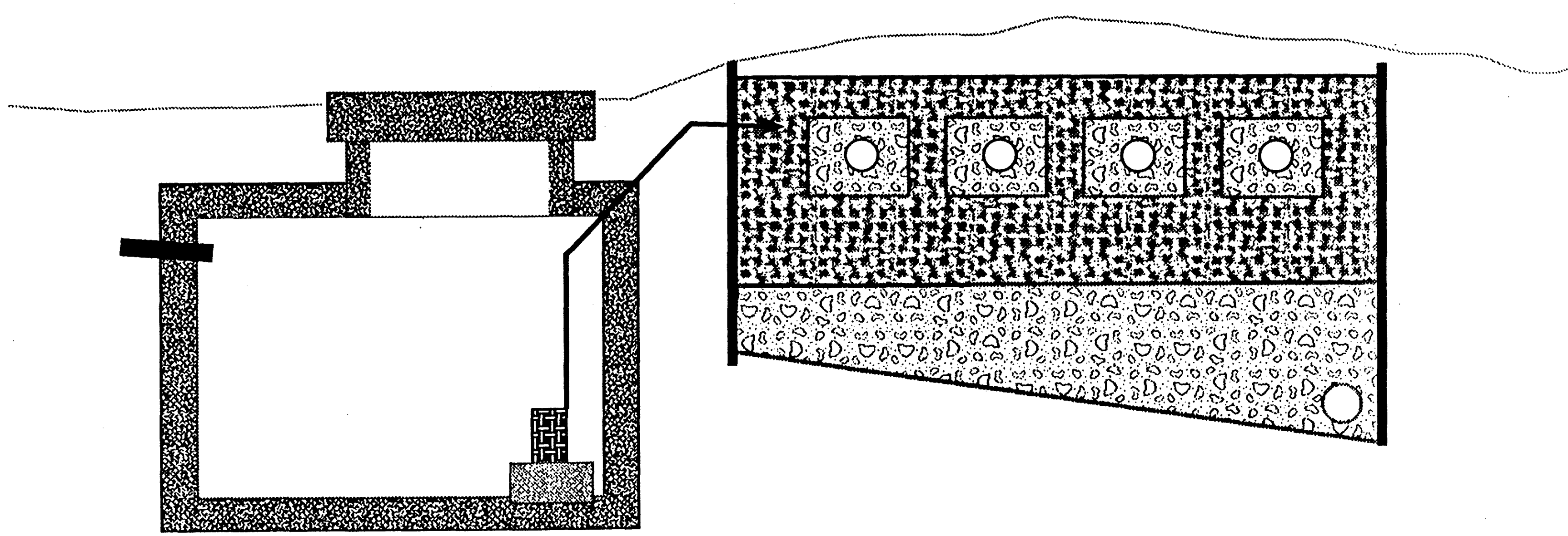
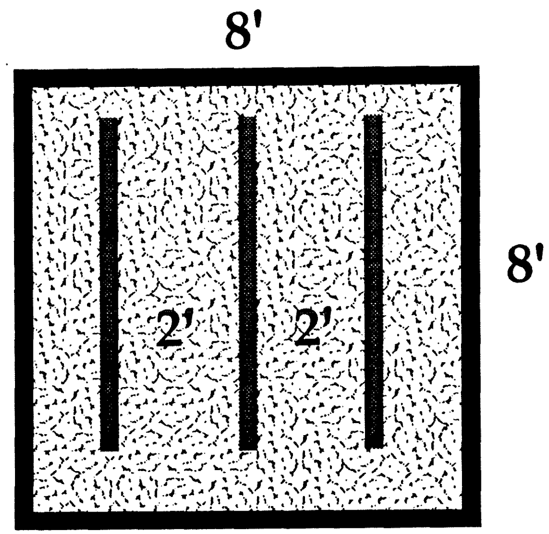


Figure 10: Peat Filter design

Recirculating Sand Filter



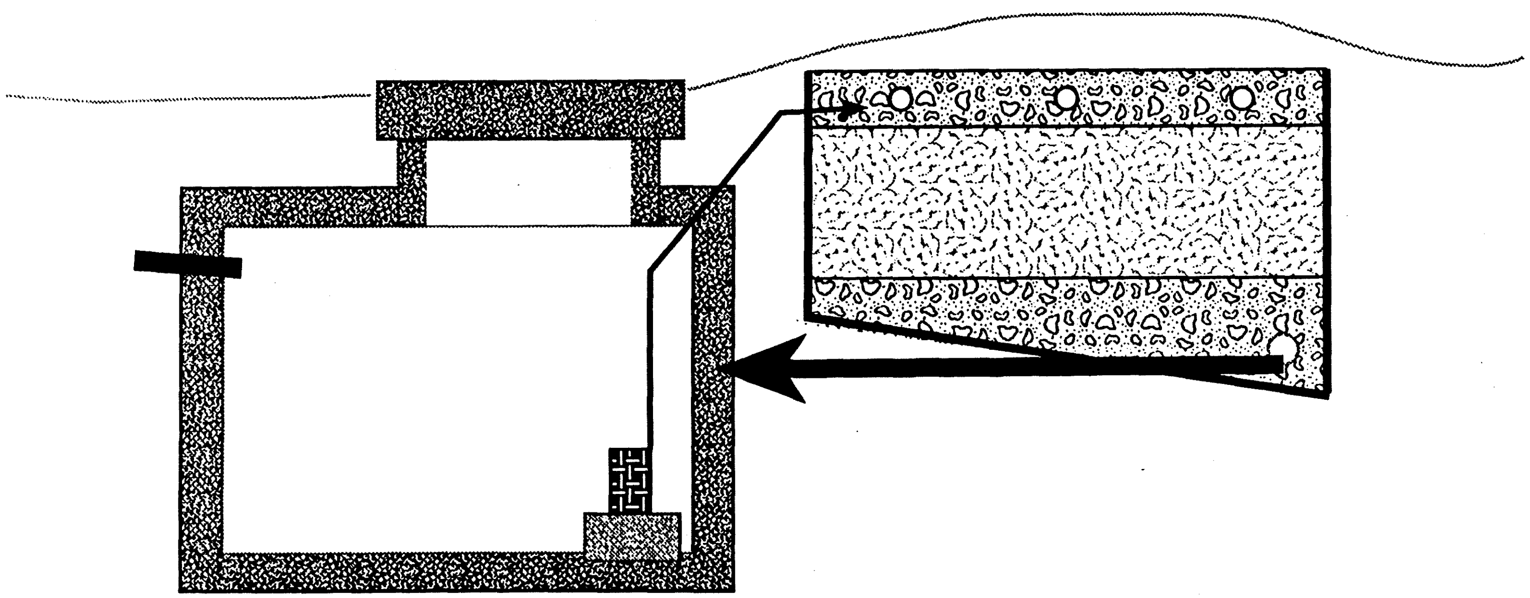
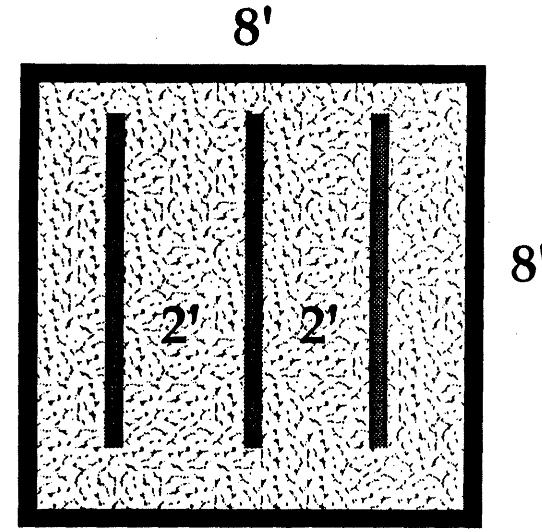


Figure 11: Recirculating Sand Filter (RSF) diagram

Recirc. Sand Filter

250 gpd (64 sqft: Loading rate 4 gpd/sqft)
Pressure distribution
2' Bird Grit
Effective Diameter = 1.5 - 2 mm
Uniformity Coeff. = 2 - 3
Gravity drain



Recirculating Sand Filter

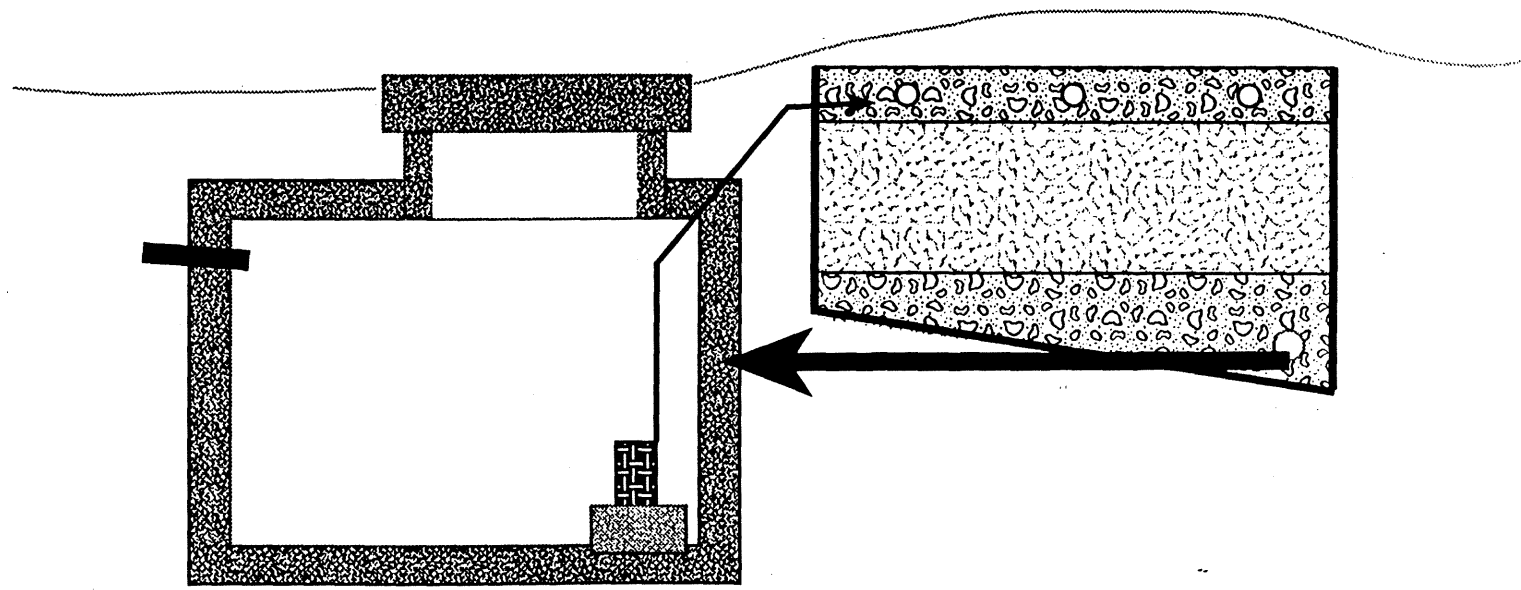
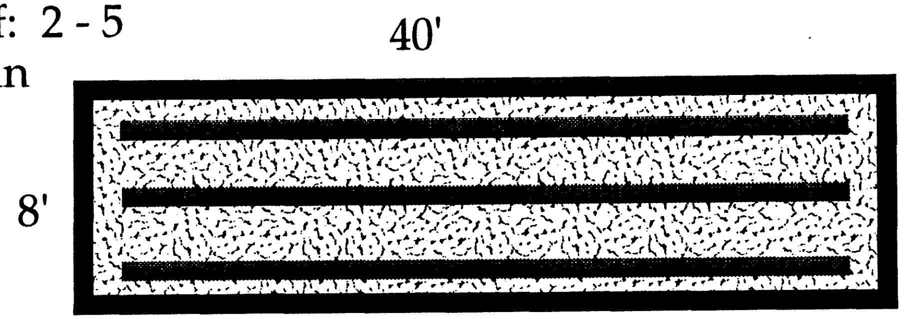


Figure 12: Recirculating Sand Filter (RSF) design

Sand Filter

250 gpd (300 sqft: Loading rate 1 gpd/sqft)
Pressure distribution
2' Clean sand (ASTM C-33)
Effective Dia: 0.25 mm
Uniformity Coeff: 2 - 5
Gravity drain



Sand Filter

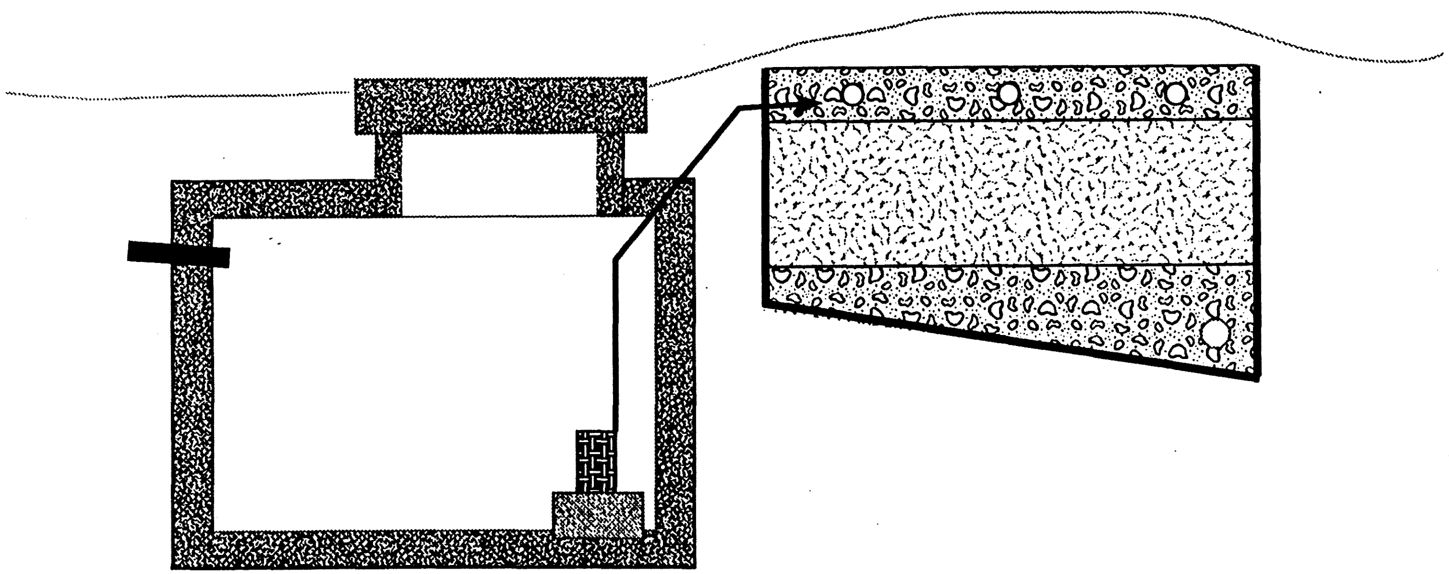


Figure 13: Sand Filter diagram

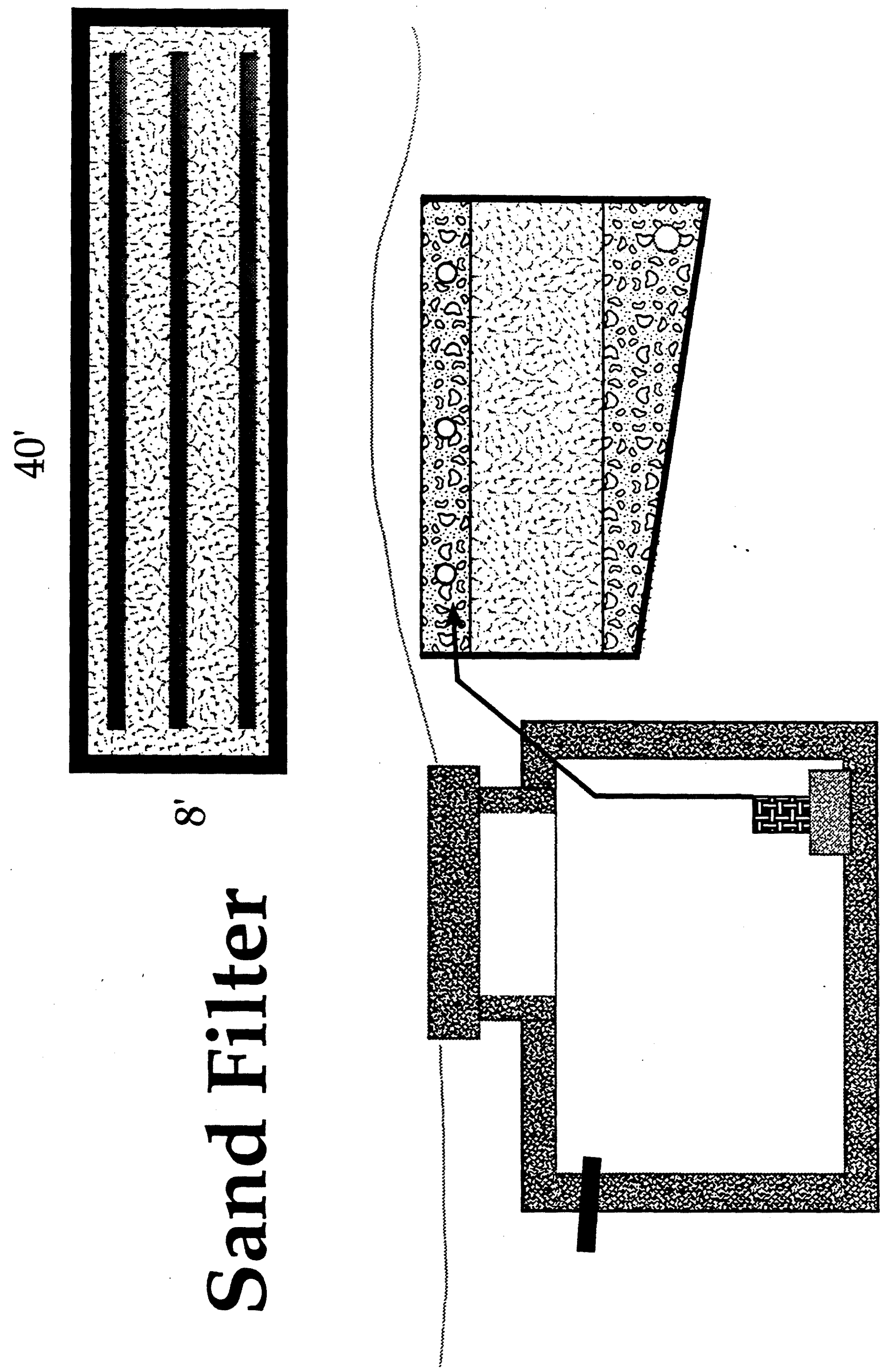


Figure 14: Sand Filter design

Constructed Wetland

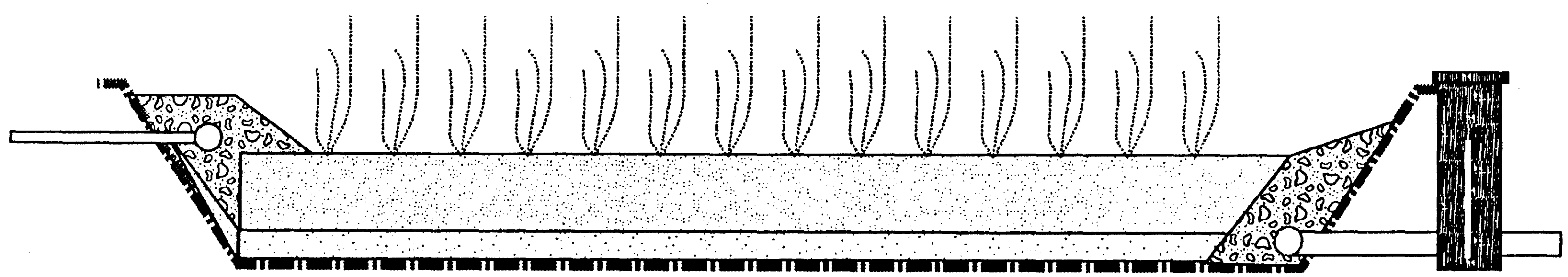
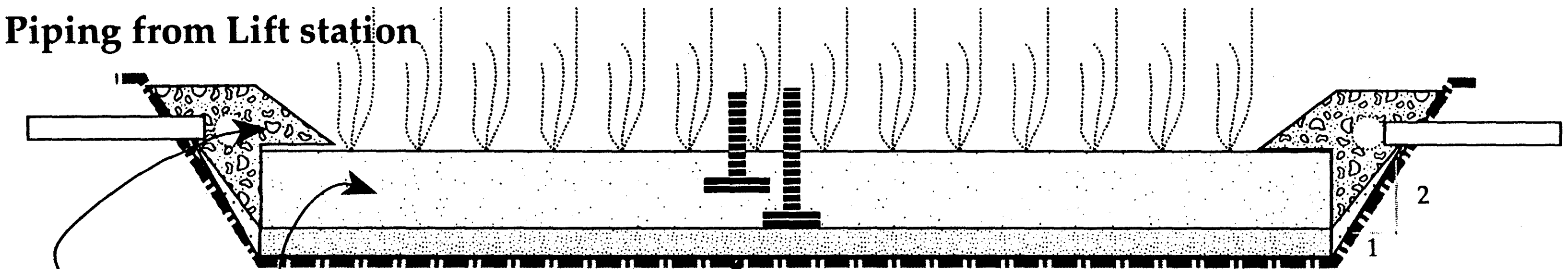


Figure 15: Constucted Wetland Diagram

Figure 16: Constucted Wetland Diagram

Constructed Wetland

Surface Area 600 sqft
(12 days x 40 cuft/day / 2 depth / 40% porosity)
16' x 60'
Timer loading
BOD loading 0.2 #pd



Pea Rock 24" (0.25"-0.5 " diameter)

Drainfield Rock encompassing 12" around the inlet and outlet pipings

Cattails 3' on center spacing

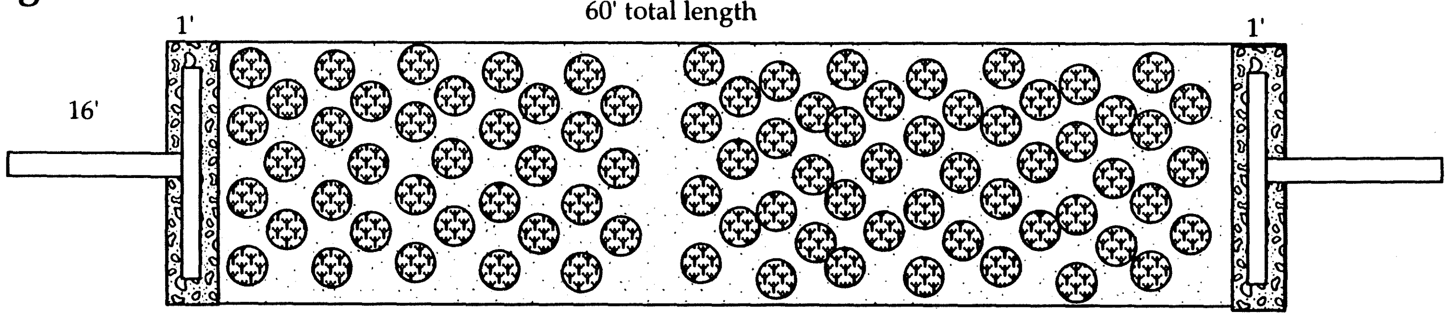
Inspection wells

Quantities:
Pea Rock: 110 cubic yards
Sand: 40 cubic yards
Drainfield Rock: 5 cubic yards
Plywood: 38 - 4' X 8'
Lining: 68' X 24'

Constructed Wetland

Surface Area 600 sqft
(13 days x 40 cuft/day / 2 depth / 40% porosity)
16' x 60'
BOD loading 0.2 #pd

Piping from Lift station



Liner 30 mil PVC

Piping to control structure maintaining depths in the system to maintain plant growth and allow for the winter depth control

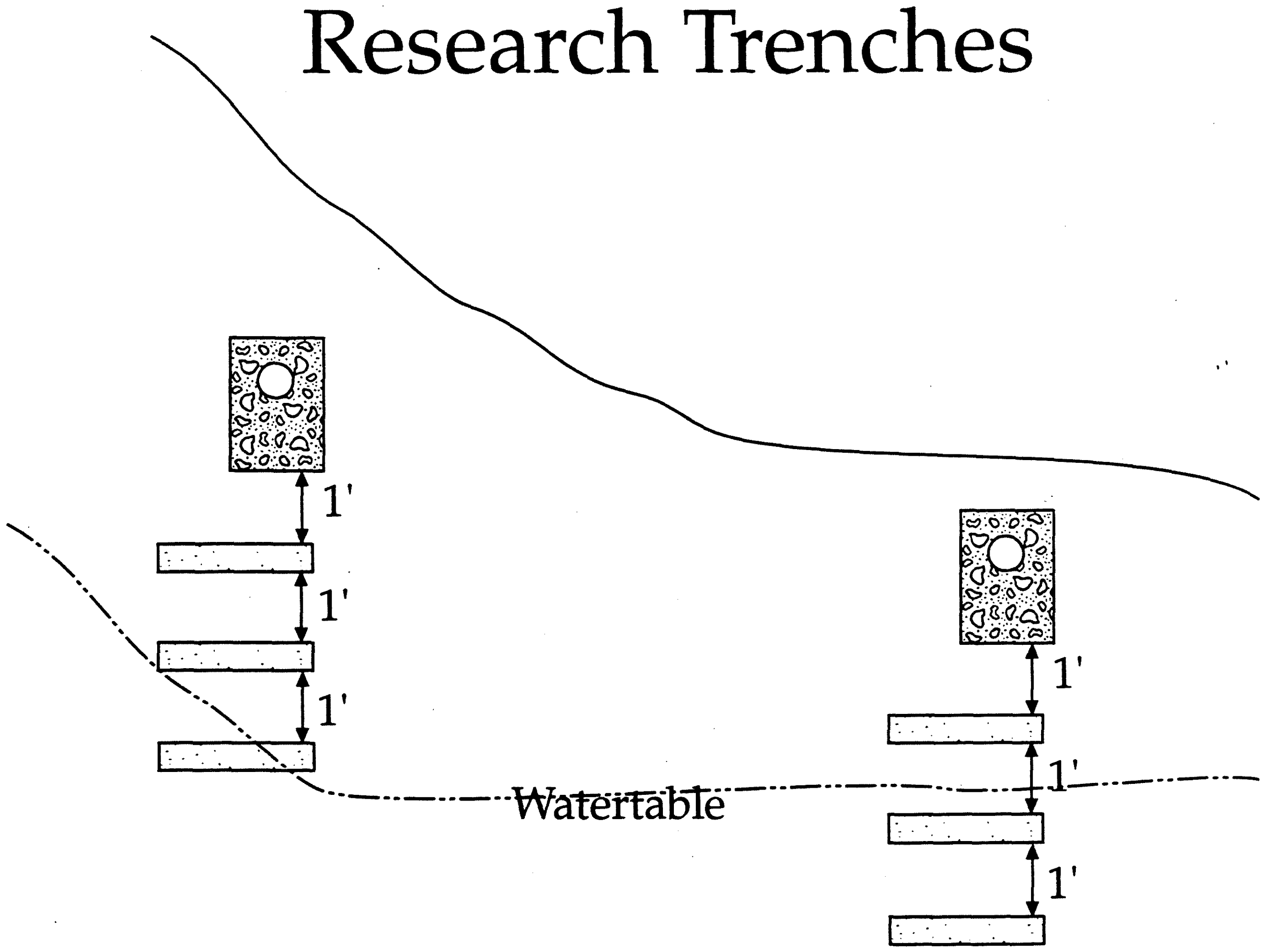
24" Pea Rock (0.25" to 0.5")

Drainfield Rock (2" - 3") encompassing 12" around the inlet and outlet pipes

Cattails 3' on center spacing

Figure 17: Constucted Wetland Design

Research Trenches



Goals:

1. Evaluate treatment effectiveness
   Septic Tank
   Treated Effluent

2. Evaluate LTAR
   Septic Tank
   Treated Effluent

Figure 18: Research trench goals

Research Trenches Construction

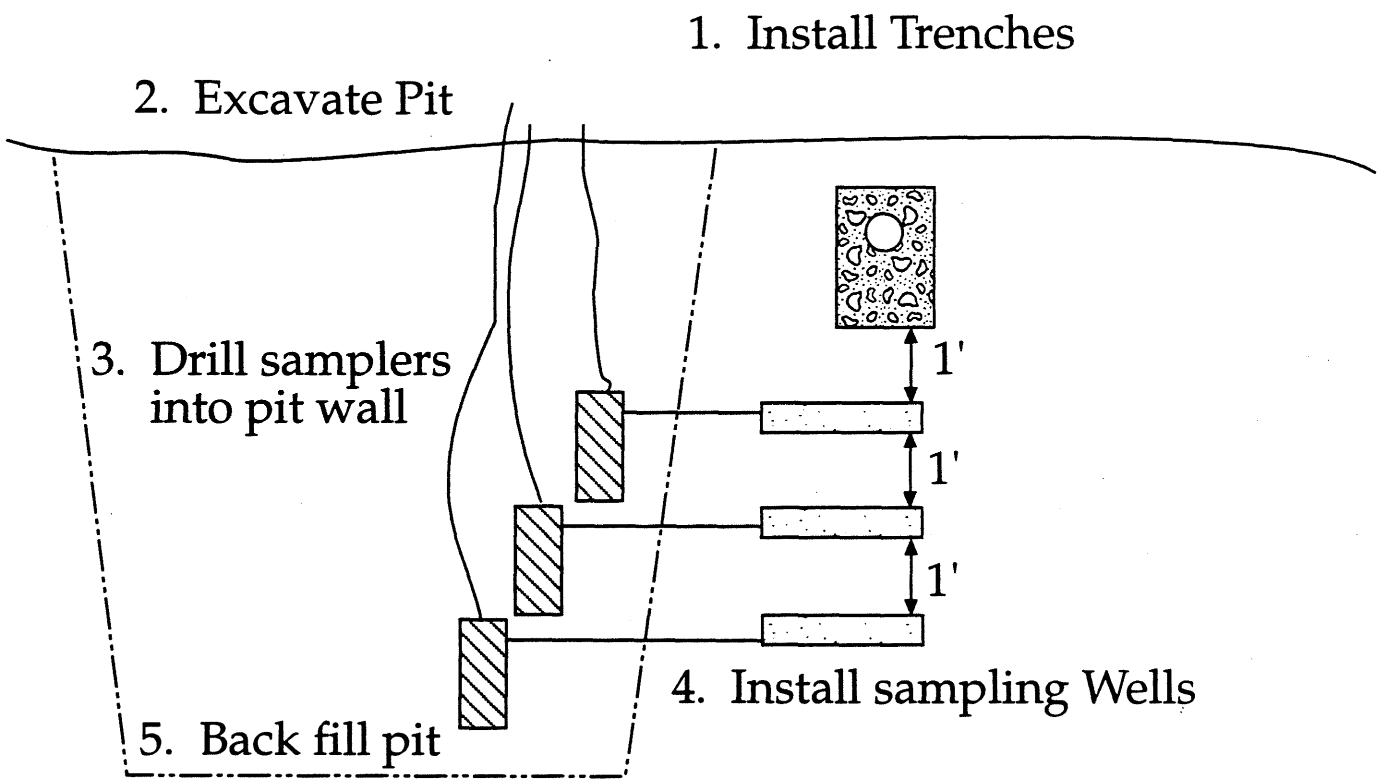


Figure 19: Research trench construction

Research Trenches

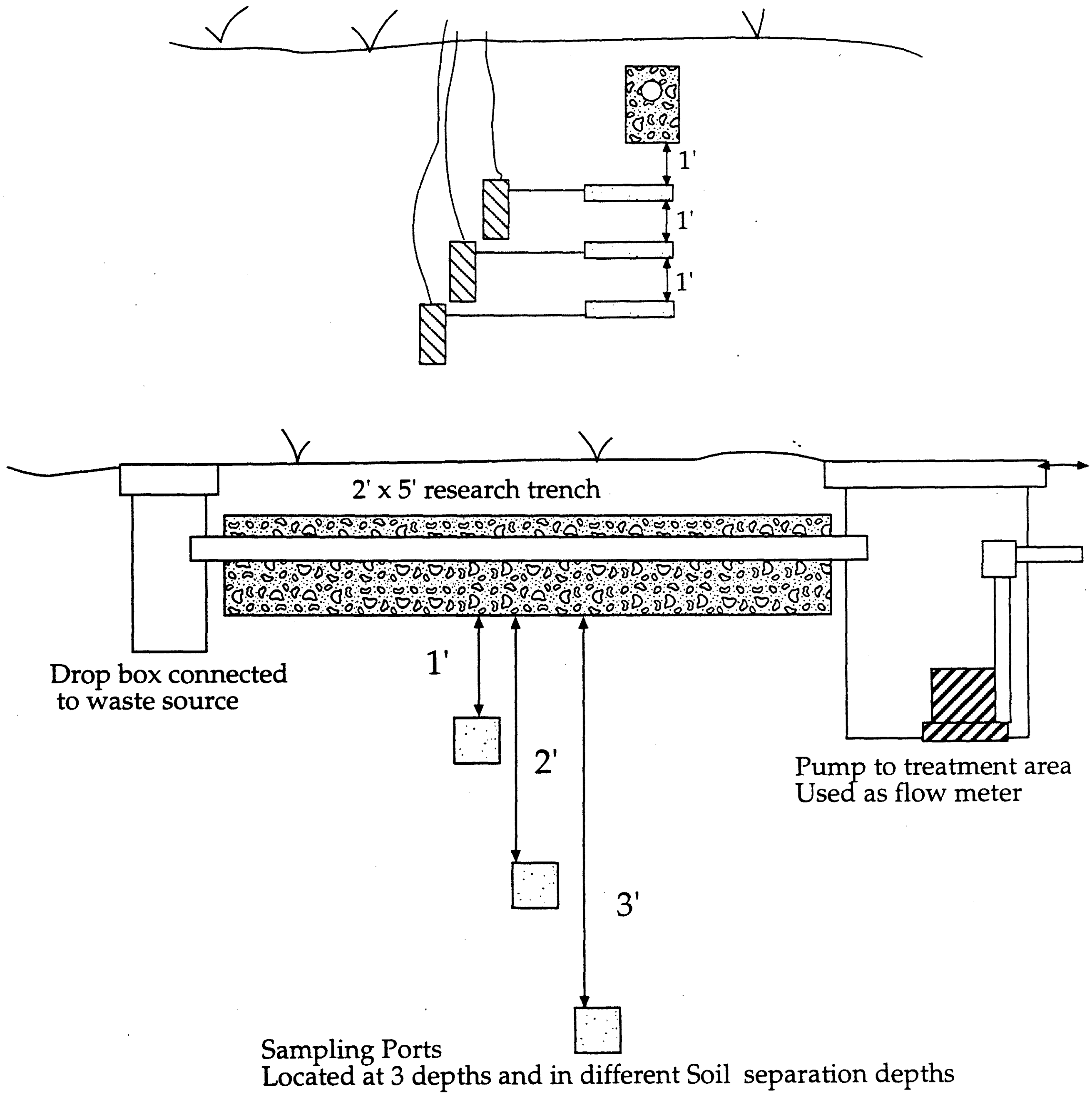
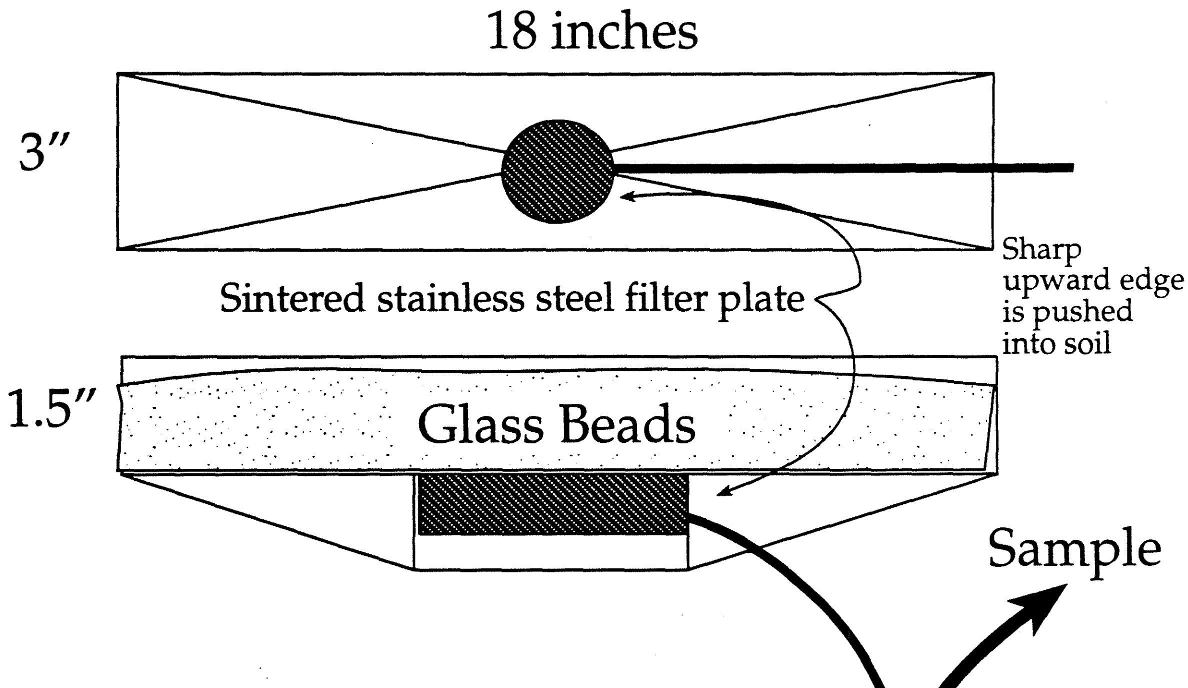
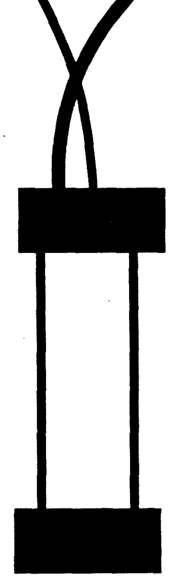


Figure 20: Research trench design

Design for an Interceptor-type Soil Water Sampler



All bottom and sidewall materials made from stainless steel sheeting. Tubing could also be made of stainless steel and welded above filter plate. With this design, suction could be applied by a hanging water column. Effluent moves downward through glass beads by gravity, but collects below the filter plate, and moves up through the plate by siphon.



Advantages:
- Known area of interception, so provides verification of LTAR.
- Will provide ability for analysis of bacteria and viruses.
- Passive sampling of unsaturated soil water.
- If porous plate becomes clogged, it could be back flushed by siphon.
- Use of water column to apply suction minimizes introduction of O_2 into system.

Disadvantage:
- Most expensive

Figure 21: Design of soil water sampler for research trenches.

Sampling Port Schematic

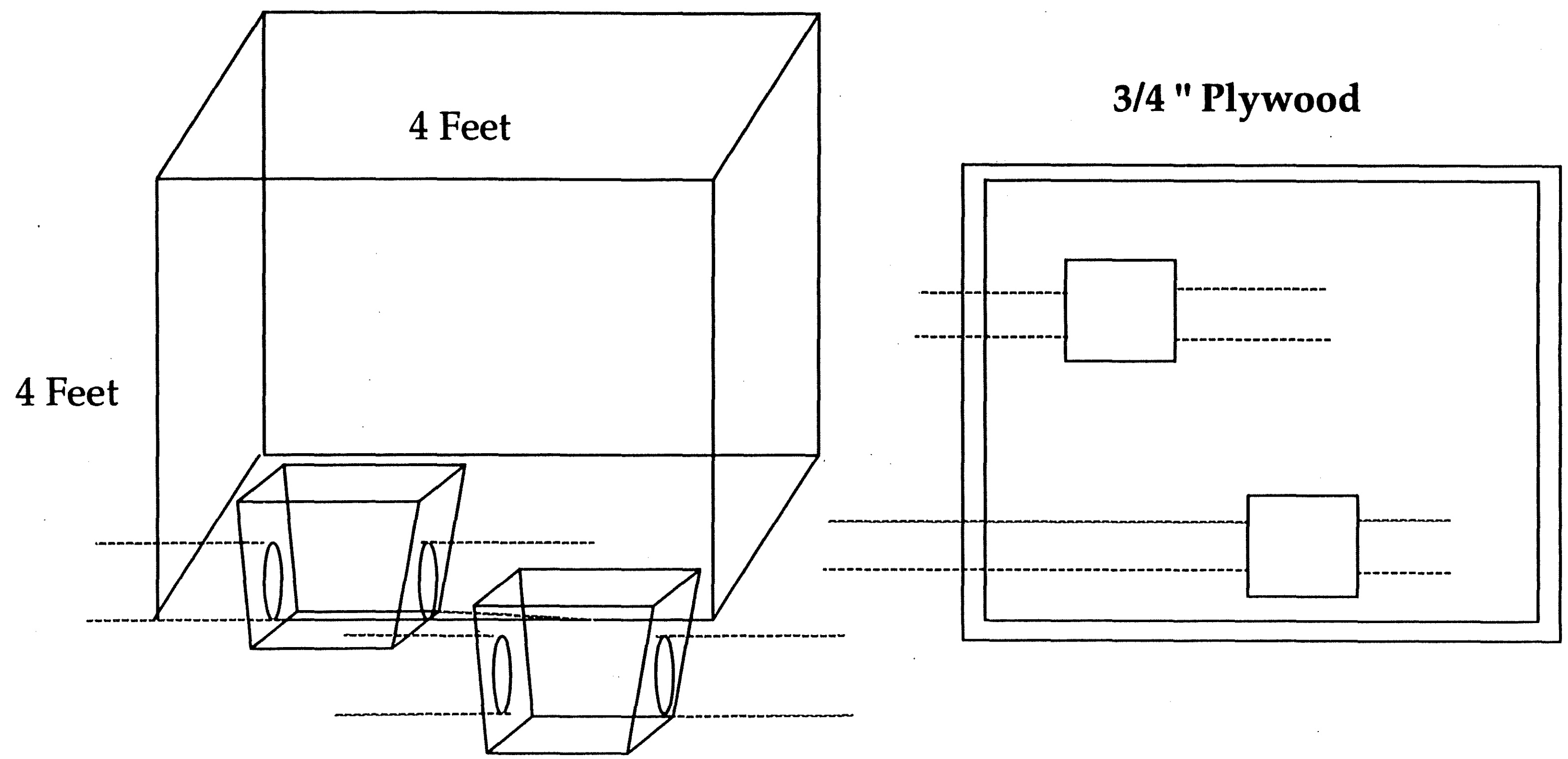
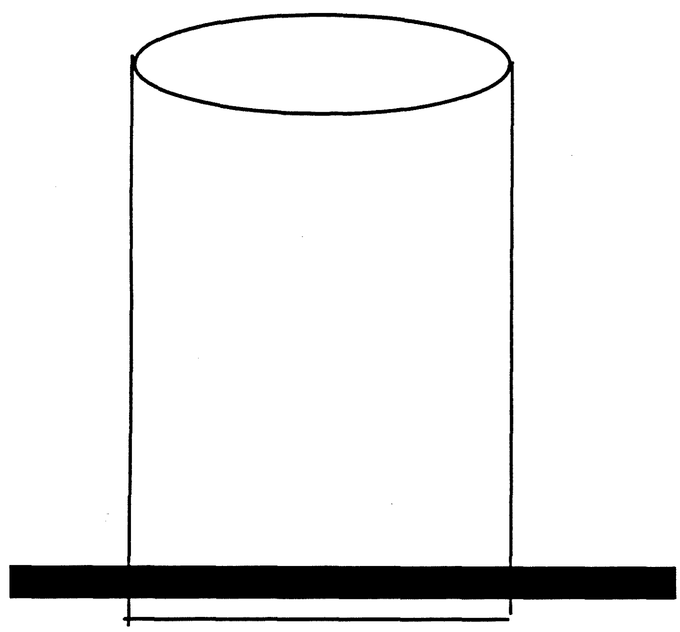


Figure 21: Sampling location

24 inch PVC Shcedule 40 pipe with a cap at the bottom



4 inch PVC pipe

Figure 22: Research sampling design

System Costs

Sewer				
Design				<u>$6,500</u>
	Survey			$2,000
	Design			$2,000
	Staking			$1,000
	Corrections			$1,500
Construction				
	Tanks			<u>$22,800</u>
		Materials		$8,000
		Excavation		$8,000
		Bedding		$1,600
		Correction		$2,000
		Renovation		$3,200
	Lift Stations (8)			<u>$22,400</u>
		Tanks		$13,000
			Materials	$4,000
			Excavation	$4,000
			Bedding	$1,000
			Correction	$1,000
			Renovation	$3,000
		Pumps		$2,800
		Controls		$2,100
		Electrical		$3,500
		Renovation		$3,000
	Piping-Sewer to Field			<u>$19,000</u>
		Materials		$4,500
		Excavation		$9,000
		Bedding		$1,500
		Correction		$1,000
		Renovation		$3,000
Sewer Total Cost				**$70,700**

Table 1: Construction costs

Soil Treatment System

Design	$5,500
Survey	$1,000
Design	$2,000
Staking	$1,000
Corrections	$1,500
Construction	$8,000
Tanks	$4,000
Materials	$1,000
Excavation	$1,000
Bedding	$500
Correction	$500
Renovation	$1,000
System	$45,180
Materials	$26,180
Excavation	$13,000
Bedding	$1,000
Renovation	$5,000
Soil Treatment System Total	**$58,680**
System Total Cost	**$129,380.00**

Costs of Septic System Aggregates
North Star Company, Kasota
(507) 387-6153

Density of Aggregates = 1.6 ons per cubic yard
Pea Rock: Eff. Dia. = 0.25 - 0.50 in.

Quantity: 174 cubic yards
Tons Required: 280 tons
Unit Cost: $7.67 per ton
Total Cost: $2147.60

Sand (ASTM C - 33)
Quantity: 92 cubic yards
Tons Required: 150 tons
Unit Cost: $4.67 per ton
Total Cost: $700.50

Drain Rock (1.5")
Quantity: 341 cubic yards
Tons Required: 5 tons
Unit Cost: $10.43 per ton
Total Cost: $5736.50

Density of Bird Grit = 1.3 tons per cubic yard

Bird Grit (#1): Eff. Dia. = 1.5 - 2 mm; Unif. Coeff. = 2 - 3
Quantity: 11 cubic yards
Tons Required: 14 tons
Unit Cost: $30 per ton
Total Cost: $420.00

Totals
Tons Required: 994 tons
Total Cost: $9004.60

Peat Costs	
Loose Peat	$8.75 cu yd
Bailed Peat	$ 4.50 bail (3.8-5.7 cu ft/ bail)
Screened Peat	$ 11.75 cu yd

Table 2: Construction material costs

Physical characterization of peat used at LW Site for the sphagnum peat filters.

Fibrous Composition	
Sphagnum & Bryopsida	30%
Ligneous (Woody)	30%
Herbaceous & Rootlets	5%
Charcoal	3%
Detritus	32%
Unrubbed fiber content	69%
Rubbed fiber content	42%
Coarse fiber (8.50-15 mm)	34%
Medium fiber (2.36-8.50 mm)	37%
Fine fiber (<2.36 mm)	29%
Other Characteristics	
Organic content	88%
Ash content	12%
Von Post degree of decomposition	H4
pH (water)	4.4
pH (CaCl)	3.6
Moisture content	60%

Table 3: Peat filter Material

Peat Filter Cost

Install Septic Tank (1,500 gal)	$1,200
Install Pump Tank (1,000 gal)	$1,000
Peat Filter Systems	
Dig Hole	$450
Plywood (8' x 40', 12 x $18.50)	$0-126
Polyvinyl Chloride Liner 20′ x 52′ = 1,800 sqft	$415
1. Piping	$ 60
2. Drain Pipe	$ 60
3. Dosing System	$ 65
4. Pea Rock (17 ton)	$315
5. Peat (45 cuyd)	$400 + $400 = $800
6. Distribution material	$ 80
7. Geotextile on Fabricated System	$ 90
8. Landscaping	$ 330
Run Electricity	$600
Dosing Pump	$300
Controls	$400
Labor and overhead costs	
Peat Filter Total Cost	**$ 6,300**

This does not include the final dispersal of the effluent
This cost would be similar to a standard trench system

Table 4: Peat filter construction costs

Recirculating Sand Filter Cost

Install Septic Tank	$1,200
Install Pump Tank	$1,000
Recirculating Sand Filter Systems	
Dig Hole	$300
Plywood (8' x 8', 4 x $18.50)	$75
Polyvinyl Chloride Liner	$210
24' x 24' = 600 sqft	
1. Piping	$60
2. Drain Pipe	$60
3. Pea Rock (7 ton)	$130
4. #2 Bird Grit (7 ton)	$130
5. Dosing System	$65
6. Drain Rock (7 ton)	$120
7. Geotextile on Fabricated System	$60
8. Cover	$100
Run Electricity	$600
Dosing Pump	$400
Controls	$600
Labor and overhead costs	
Recirculating Sand Filter Total Cost	**$5,200**

This does not include the final dispersal of the effluent
This cost would be similar to a standard trench system

Table 5: RSF construction costs

Sand Filter Cost

Install Septic Tank (1,500 gal)	$1,200
Install Pump Tank (1,000 gal)	$1,000
Sand Filter Systems	
Dig Hole	$500
Plywood (8' x 40', 12 x $18.50)	$0-126
Polyvinyl Chloride Liner	$415
30' x 60' = 1,800 sqft	
1. Piping	$ 60
2. Drain Pipe	$ 60
3. Dosing System	$ 65
4. Pea Rock (17 ton)	$315
5. Sand (34 ton)	$620
6. Distribution material	$ 80
7. Geotextile on Fabricated System	$ 90
8. Landscaping	$ 330
Run Electricity	$600
Dosing Pump	$300
Controls	$400
Labor and overhead costs	
Sand Filter Total Cost	**$ 6,200**

This does not include the final dispersal of the effluent
This cost would be similar to a standard trench system

Table 6: Sand filter construction costs

Sand Filter Media

Sieve No.	Particle Size (mm)	**Filter Sand** % passing	ASTM C-33
3/8	9.5	**100**	100
4	4.75	**100**	95-100
8	2.36	**85**	80-100
10	2.0	**66**	
16	1.18	**46**	55-85
20	0.85	**33**	
30	0.6	**26**	30-60
50	0.3	**10**	5-30
100	0.15	**4**	0-10
200	0.08	**1**	

Table 7: Sand filter material

Constructed Wetland Cost

Install Septic Tank	$1,200
Install Pump Tank	$1,000
Wetland Systems	
Dig Hole	$600
Plywood (16' x 60', 20 x $18.50)	$370
Polyvinyl Chloride Liner	$460-560
30' x 40' = 1,200 sqft	
30' x 50' = 1,500 sqft	
1. Piping	$ 60
2. Drain Pipe	$ 60
3. Dosing System	$ 65
4. Pea Rock (117 ton)	$2160
5. Plants & Rhizomes@ 1' spacing	$320
6. Distribution material	$ 80
7. Geotextile on Fabricated System	$ 90
8. Landscaping	$ 330
Run Electricity	$600
Dosing Pump	$250
Controls	$400
Labor and overhead costs	
Wetland Filter Total Cost	**$8,150**

This does not include the final dispersal of the effluent
This cost would be similar to a standard trench system

Table 8: Constructed Wetland construction cost

Pea Rock

Sieve Opening (mm)	% Retained	% Finer
4.766	62.3	37.1
3.36	28.6	9.1
1.70	8.0	1.1
1.18	0.87	0.3
-	0.3	-

Drainfield Rock

26.67	22.74	77.2
18.85	62.20	15.1
9.423	15.07	-

#2 Bird Grit

4.766	2.16	97.84
3.36	31.3	66.54
1.7	54.8	11.74
1.18	7.1	4.64
0.850	1.6	3.04
0.420	1.5	1.54
-	1.5	-

Table 9: Filter material

Lake Washington Gravity Peat Filter

Period	Inflow 11/1/96-6/10/97	Outflow 11/1/96-6/10/97	% Removal 11/1/96-6/10/97
TKN (mg/L)	34.59 (13.5)	12.91 (7.9)	62.7
(NO3+NO2)-N	0.113 (0.29)	12.85 (6.5)	
NH3 (mg/L)	26.26 (9.84)	4.98 (4.2)	81.3
BOD (mg/L)	99.18 (47.6)	23.61 (27.8)	76.2
Chloride (mg/L)	610.73 (221.4)	413.99 (142.4)	32.2
Total P (mg/L)	5.11 (1.86)	1.32 (0.38)	
TSS (mg/L)	123.5 (235.1)	54.92 (90.1)	74.2
CRR (mg/L)	164.75 (402)	166.58 (389.1)	55.5
Fecal Coliforms (CFU/100 ml)	560818 (404666)	282.1 (488)	99.9

Lake Washington Pressure Peat Filter

Period	Inflow 11/1/96-6/10/97	Outflow 11/1/96-6/10/97	% Removal 11/1/96-6/10/97
TKN (mg/L)	34.59 (13.5)	3.78 (1.94)	89.1
(NO3+NO2)-N	0.113 (0.29)	1.09 (0.97)	
NH3 (mg/L)	26.26 (9.84)	1.48 (1.2)	94.4
BOD (mg/L)	99.18 (47.6)	17.77 (12.03)	82.1
Chloride (mg/L)	610.73 (221.4)	295.03 (119.2)	51.7
Total P (mg/L)	5.11 (1.86)	0.22 (0.10)	95.7
TSS (mg/L)	123.5 (235.1)	92.67 (95.2)	30.0
CRR (mg/L)	164.75 (402)	46.33 (45.7)	71.9
Fecal Coliforms (CFU/100 ml)	560818 (404666)	1761.4 (3879)	99.7

Table 10: Peat filter performance

Lake Washington Constructed Wetland 1

Period	Inflow 11/1/96-6/10/97	Outflow 11/1/96-6/10/97	% Removal 11/1/96-6/10/97
TKN (mg/L)	34.59 (13.5)	14.38 (8.7)	58.4
(NO3+NO2)-N	0.113 (0.29)	1.05 (1.37)	
NH3 (mg/L)	26.26 (9.84)	15.16 (5.8)	42.2
BOD (mg/L)	99.18 (47.6)	7.57 (3.79)	92.4
Chloride (mg/L)	610.73 (221.4)	429.06 (121.03)	29.7
Total P (mg/L)	5.11 (1.86)	0.13 (0.07)	97.5
TSS (mg/L)	123.5 (235.1)	9.43 (3.46)	30
CRR (mg/L)	164.75 (402)	12.17(5.5)	92.6
Fecal Coliforms (CFU/100 ml)	560818 (404666)	1127.3 (2593)	99.8

Lake Washington Constructed Wetland 2

Period	Inflow 11/1/96-6/10/97	Outflow 11/1/96-6/10/97	% Removal 11/1/96-6/10/97
TKN (mg/L)	34.59 (13.5)	6.94 (6.1)	79.9
(NO3+NO2)-N	0.113 (0.29)	0.84 (0.91)	
NH3 (mg/L)	26.26 (9.84)	7.68 (5.2)	70.8
BOD (mg/L)	99.18 (47.6)	5.43 (2.31)	94.5
Chloride (mg/L)	610.73 (221.4)	338.53 (88.1)	44.6
Total P (mg/L)	5.11 (1.86)	0.09 (0.085)	98.2
TSS (mg/L)	123.5 (235.1)	13.29 (15.6)	89.2
CRR (mg/L)	164.75 (402)	22.57 (27.5)	86.3
Fecal Coliforms (CFU/100 ml)	560818 (404666)	127.83 (135)	99.9

Table 11: Constructer wetland performance

Lake Washington Recirculating Sand Filter 1

Period	Inflow 11/1/96-6/10/97	Outflow 11/1/96-6/10/97	% Removal 11/1/96-6/10/97
TKN (mg/L)	34.59 (13.5)	0.96 (0.57)	97.2
(NO3+NO2)-N	0.113 (0.29)	18.26 (14.9)	
NH3 (mg/L)	26.26 (9.84)	0.18 (0.2)	70.8
BOD (mg/L)	99.18 (47.6)	8.6 (11.5)	91.3
Chloride (mg/L)	610.73 (221.4)	230.7 (198.2)	62.2
Total P (mg/L)	5.11 (1.86)	1.05 (0.76)	79.5
TSS (mg/L)	123.5 (235.1)	31.83 (66.2)	74.2
CRR (mg/L)	164.75 (402)	5.14 (3.02)	96.9
Fecal Coliforms (CFU/100 ml)	560818 (404666)	30.67 (50.6)	100

Lake Washington Recirculating Sand Filter 2

Period	Inflow 11/1/96-6/10/97	Outflow 11/1/96-6/10/97	% Removal 11/1/96-6/10/97
TKN (mg/L)	34.59 (13.5)	3.51 (3.7)	89.9
(NO3+NO2)-N	0.113 (0.29)	9.92 (4.3)	
NH3 (mg/L)	26.26 (9.84)	2.71 (3.16)	89.7
BOD (mg/L)	99.18 (47.6)	18.75(15.8)	81.8
Chloride (mg/L)	610.73 (221.4)	330.73 (84.6)	45.9
Total P (mg/L)	5.11 (1.86)	1.26 (0.31)	75.3
TSS (mg/L)	123.5 (235.1)	31.44 (54.7)	74.5
CRR (mg/L)	164.75 (402)	19.89 (28.9)	87.9
Fecal Coliforms (CFU/100 ml)	560818 (404666)	35816 (78649)	93.6

Table 12: RSF performance

Lake Washington Sand Filter 1

Period	Inflow 11/1/96-6/10/97	Outflow 11/1/96-6/10/97	% Removal 11/1/96-6/10/97
TKN (mg/L)	34.59 (13.5)	5.12 (6.6)	85.2
(NO3+NO2)-N	0.113 (0.29)	21.21 (13.16)	
NH3 (mg/L)	26.26 (9.84)	3.59 (4.96)	86.3
BOD (mg/L)	99.18 (47.6)	19.2 (17.5)	80.6
Chloride (mg/L)	610.73 (221.4)	902.03 (1282.9)	
Total P (mg/L)	5.11 (1.86)	2 (1.07)	60.9
TSS (mg/L)	123.5 (235.1)	176.58 (487.1)	
CRR (mg/L)	164.75 (402)	49.92 (116)	69.7
Fecal Coliforms (CFU/100 ml)	560818 (404666)	42442 (97484)	92.4

Lake Washington Sand Filter 2

Period	Inflow 11/1/96-6/10/97	Outflow 11/1/96-6/10/97	% Removal 11/1/96-6/10/97
TKN (mg/L)	34.59 (13.5)	7.04 (12.86)	79.6
(NO3+NO2)-N	0.113 (0.29)	19.5 (13.4)	
NH3 (mg/L)	26.26 (9.84)	4.44 (7.2)	83.1
BOD (mg/L)	99.18 (47.6)	16.41 (21.6)	83.5
Chloride (mg/L)	610.73 (221.4)	503.77 (142.5)	17.5
Total P (mg/L)	5.11 (1.86)	1.57 (1.15)	69.3
TSS (mg/L)	123.5 (235.1)	16.83 (28.1)	86.4
CRR (mg/L)	164.75 (402)	52.5 (147.5)	68.1
Fecal Coliforms (CFU/100 ml)	560818 (404666)	101302 (305195)	81.9

Table 13: Sand filter performance

Training events at the Site

Field days for construction and training

MOSTCA summer picnic

MPCA Staff visits

Open house for homeowners

Open house for Lake association members and County Commissioners

ASEA tour for National guests

Other training impacts

Workshop training sessions

- MOSTCA winter convention
- U of MN Continuing Education workshops
- U of MN Design Workshop
- ISTS meeting
- 7080 changes dealing with Experimental Systems

Table 14: Training activities

Table 15: Soil profile

Soil Pit #1 LeSueur clay loam

Landform:	Uplands
Parent material	Glacial Till
Slope:	1 to 4 percent
Depth	**Description**
0 to 6 inches	Very dark grayish brown (2.5 Y 3/2) clay loam; weak fine granular structure
6 to 16 inches	Dark brown (10YR 4/3) clay loam; moderate fine subangular blocky structure
16 to 26 inches	Olive brown (2.5 Y 4/4) clay loam; few fine distinct grayish brown (2.5 Y 5/2) mottles; moderate medium subangular blocky structure
26 to 45 inches	Dark grayish brown (2.5 Y 4/2) clay loam; common fine distinct olive brown (2.5 Y 4/4) and common fine faint grayish brown (2.5 Y 5/2) mottles; weak medium subangular blocky structure
45 to 60 inches	Grayish brown (2.5 Y 5/2) clay loam; common fine distinct strong brown (7.5 YR 5/6) mottles; massive, friable structure

Soil Pit #2 Cordova clay loam

Landform:	Uplands
Parent material	Glacial Till
Slope:	0 to 2 percent
Depth	**Description**
0 to 9 inches	Very dark grayish brown (2.5 Y 3/2) clay loam; moderate fine subangular blocky structure
9 to 18 inches	Black (2.5 Y 2/1) clay loam; moderate fine subangular blocky structure
18 to 24 inches	Very dark grayish brown (2.5 Y 3/2) clay loam; moderate medium subangular blocky structure
24 to 30 inches	Olive brown (2.5 Y 4/4) clay loam; common fine prominent dark gray (5 Y 4/1) mottles; moderate medium prismatic structure
30 to 60 inches	Olive gray (5 Y 5/2) clay loam; common medium prominent olive brown (2.5 Y 4/4) and yellowish brown (10 YR 5/8) mottles; massive, friable structure

Table 15: Soil profile