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TECHNICAL COMPLETION REPORT

January 1997

TITLE: EVALUATION OF SHALLOW SOIL ABSORPTION FIELDS RECEIVING RECIRCULATED SAND FILTER WASTEWATER EFFLUENT

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EXECUTIVE SUMMARY

EVALUATION OF SHALLOW SOIL ABSORPTION FIELDS RECEIVING RECIRCULATED SAND FILTER WASTEWATER EFFLUENT

Three shallow, low-pressure dosed soil absorption fields receiving wastewater from septic tank systems using recirculating sand filters were evaluated for treatment effectiveness in removal of inorganic nitrogen and fecal coliform bacteria. At the location of these sites, Washington Island, WI, groundwater quality is threatened by on-site disposal because of the shallow, coarse soil and fractured bedrock present. This study is a follow-up to research conducted on the effluent from advanced-design on-site wastewater disposal systems prior to absorption field disposal.

The levels of inorganic N in the soil water (vadose zone) was determined on water collected using four suction lysimeters installed beneath each of three absorption fields. Nitrate-N and ammonia-N levels averaged 2.7 mg/L NO_3^-N and 0.1 mg/L NH₃-N for a residential site, 9.4 mg/L NO_3^-N and 0.1 mg/L NH₃-N for a commercial grocer/meat processing site, and 1.6 mg/L NO_3^-N and 6.2 mg/L NH₃-N at a newly-installed residential site system respectively. Nitrate levels ranged widely at the commercial site.

To obtain information on the distribution of fecal coliform and to further evaluate nitrogen removal, soil samples were collected in the absorption field directly beneath a dosing point in the distribution pipe. Fecal coliform levels in these profiles fell essentially to undetectable levels after passing through 24 in. (60 cm) of soil. Chemical analysis of soil profiles [14 to 25 in. (35 to 62.5 cm)] below dosing points indicate ammonia-N levels of only a few mg/kg. In the same profiles nitrate-N levels decreased with depth and the nitrate-N to chloride ratios decreased, suggesting that some denitrification occurs below the absorption field.

Soils below absorption systems associated with septic systems using recirculating sand filters were found to have lower levels of ammonia-N and fecal coliform bacteria than conventional septic tank systems. In addition to discharging effluent with 70 to 90 percent lower total nitrogen content, recirculating sand filter systems also appear to have the advantage that nearly all the inorganic nitrogen is in the form of nitrate when applied to the absorption field which is partially denitrified in the receiving soil.

INTRODUCTION

The 1990, U.S. Census lists 25.9 million households across the United States that use on-site wastewater disposal systems (OSWDS). This was 24% of the total households in the census and an increase of more than three million since 1980 (Bureau of Census, 1990). In addition, the number of OSWDS is expected to rise because of suburban sprawl and the expense and time required to construct municipal wastewater systems (Burkes and Minnis, 1994). The most common OSWDS is a conventional septic tank with a subsurface soil absorption system (Reneau et al., 1989).

Installation in "poor" soils and increased septic tank density are cited as the primary reasons for groundwater contamination by septic systems (ljzerman et al., 1992). Contamination occurs when untreated septic tank discharge leaches into groundwater. This is a large problem because groundwater supplies one fourth of the freshwater used in the U.S. and is the primary source of drinking water for many major cities and most of the rural population (Keeney, 1986).

Domestic wastewater contains bacteria, viruses and parasites pathogenic to humans if ingested (Hagedom, 1984). Bacteria are responsible for several wastewater related diseases, including typhoid, paratyphoid, bacillary dysentery, gastroenteritis and cholera. Hepatitis A, polio and viral gastroenteritis are a few diseases that can be contracted from viruses in wastewater, and parasites, including helminths and protozoans, can cause mild to severe diarrhea. An estimated 43 percent of disease outbreaks caused by pathogenic bacteria and viruses from 1970-1977 were traced to drinking untreated groundwater (Craun, 1985). These types of outbreaks have been linked to drinking water contaminated with effluent from septic systems (Burkes and Minnis, 1994).

Nitrate contaminated groundwater is also a public health concern and

environmental concern. First, NO_3 -N is a nutrient for algae and other aquatic green plants, therefore, the presence of excess NO_3 -N can contribute to eutrophication in surface waters. Second, NO_3 -N in drinking water has been linked to the illness methemoglobinemia, affecting infants primarily under the age of six months. This condition occurs because the higher pH in the baby's intestinal tract promotes bacteria that can convert NO_3 -N to NO_2 -N. In the bloodstream, NO_2 -N can combine with hemoglobin to form methemoglobin, which cannot carry oxygen (Burkes and Minnis, 1994). As a result the baby suffocates from lack of oxygen. In general, septic tank effluent contains nitrogen in the form of ammonium and nitrate ions. Because the surfaces of soil particles are typically negatively charged, nitrate ions are not retained by soil. Hence, nitrate is readily leached into groundwater. Depending on soil conditions, typically little or no attenuation of NO_3 -N levels occurs. Across the U.S., NO_3 -N at levels exceeding the EPA drinking water standard of 10 mg/L, has leached into groundwater and threatens water supplies, especially in areas of thin soils (Cogger 1988).

The objective of this study was to determine the levels of nitrogen and fecal coliform in the vadose zone beneath the soil absorption systems of three advanced-design on-site wastewater disposal systems on Washington Island, Wisconsin. (A generalized schematic diagram of the type of system installed on Washington Island is shown in Figure 1.) This was done to evaluate the quality of the absorption field effluent that is discharged to groundwater following treatment in these wastewater disposal systems and percolation through the soil. Parameters of specific interest include NH₃-N, NO₃-N, TKN, Cl⁻ and fecal coliform bacteria as an indicator organism of human pathogens. . С. н. а.



Figure 1. Modified Conventional Recirculating Sand Filter System (Venhuizen, 1995)

Washington Island, Wisconsin

Washington Island, Wisconsin is located in Door County off the tip of the Door Peninsula in Lake Michigan. It is approximately 33 mi² (8547 hectares), with 278 year round residences and 530 seasonal residences (Venhuizen, 1995). Residents and tourists on the island rely on untreated groundwater as the source of drinking water; and conventional septic systems and holding tanks are the form of wastewater disposal.

Two unique factors in the physical setting make Washington Island susceptible to groundwater contamination. First, much of the island has thin, unconsolidated sediments, less than 80 in (2 m) in most places, that consist primarily of sandy, loam type soils (Williams, 1995; Link et al., 1978). The second physical factor contributing to groundwater contamination is the nature of the underlying dolostone bedrock. The Township draws its water from a dolomitic aquifer consisting of two series of Silurian dolostone. The Silurian dolostone has well-developed vertical and horizontal fractures which have been enlarged by karstification processes (Johnson and Stieglitz, 1990).

These fractures can create a rapid direct conduit for seepage from the on-site wastewater systems into groundwater.

Methods of treatment currently recognized in Wisconsin codes could not be implemented on many sites in the township due to lack of adequate soil depth to a limiting condition. Currently the "adequate" depth of soil in Wisconsin is three feet (Burkes and Minnis, 1994). These rules, administered by the Wisconsin Department of Industry, Labor and Human Relations-now Department of Commerce-presume that, given the presence of a prescribed soil depth between the bottom of the disposal trench and a limiting condition, adequate attenuation of the wastewater will occur, and the environment and the public health will be protected. However, this code has been under attack for many years as being inadequate to comply with Chapter NR 140 of the Wisconsin Codes, as well as leaving little room for new OSWDS technology to gain acceptance. NR 140 is the code which sets limits for many substances which may pollute groundwater. The Department of Commerce is presently in the process of revising the "3 feet rule"; and currently the general approach favored by The Department of Commerce is to prescribe compliance with NR 140 as the required level of performance, rather than prescribe specific system configurations which are presumed to attain compliance (Venhuizen, 1995). As of late 1996, however, these changes have not been implemented.

In 1991, with permission from the state of Wisconsin, the Town of Washington Island decided to investigate experimental on-site wastewater systems which used methods of treatment outside the "prescription" of the current code. David Venhuizen, a consulting engineer, was hired to design several advanced on-site wastewater disposal systems to replace the current septic and holding tanks. To fund this effort, the township applied to the Wisconsin Department of Natural Resources (WDNR) through the Federal

Clean Water Fund.

Funds were approved in January 1992, for the project to get underway. The systems designed by Venhuizen were to provide better pretreatment than what is possible with conventional septic tanks, and to use disposal methods which maximize the treatment capabilities of the limited soil on the island (Venhuizen, 1994b). Specifically, these systems utilize recirculating sand filters and shallow, low-pressure dosed disposal fields.

The goal of the project, which was overseen by WDNR and DILHR, was to provide cost effective wastewater treatment while ensuring that the alternative systems comply with the groundwater quality enforcement standards (Venhuizen, 1995). Therefore, Washington Island Township was required to demonstrate that these advanced OSWDS could comply with Wisconsin Code NR 140. To accomplish this, the effectiveness of these alternative systems, which are designed to remove a substantial portion of the nitrogen compounds and reduce coliform bacteria levels in the septic effluent, had to be established.

In 1992, seven advanced systems were installed on Washington Island. Six were at private homes and one at a commercial grocery store. The systems were evaluated for a two year period, from July 1992 through June 1994 by investigators at the University of Wisconsin-Green Bay. Data collected from five demonstration sites between September 1992 and August 1993 was analyzed at University of Wisconsin-Green Bay. From this data it was established that:

When proper operating conditions are maintained, the recirculating sand filter concept used in these demonstration systems will produce an effluent with typical BOD₅ and TSS concentrations of <10 mg/L and with typical total nitrogen concentrations of <20 mg/L, perhaps even consistently <15 mg/L. BOD₅ removal rate is expected to be in excess of 95%, TSS removal rate is expected to be in excess of 90%, and total nitrogen removal rate is expected to be in excess of 65%. Effluent coliform counts may be erratic, but the concept appears capable of consistently producing counts in the range of 10^3

CFU/100 mL (Venhuizen, 1994a).

Williams (1995) states that it is probable that the residual nitrogen entering the absorption field of these systems will eventually be converted to NO₃-N via nitrification processes. Because of this, on their own the systems are not removing enough nitrogen in order to meet the drinking water standards set in NR 140. Wisconsin Administration Code, NR 140 states NO₃-N must be less than 10 mg/L and fecal coliform must be less than 1 CFU/100 mL. Initial efforts to assess the additional treatment provided by the shallow absorption fields used with these systems was unsuccessful. Therefore, the levels of nitrogen and fecal coliform entering the groundwater under the absorption field is unknown. Due to this, the governing bodies that regulate septic systems are holding the systems accountable to the drinking water standards at the point where the effluent leaves the sand filter, giving no credit for wastewater treatment to the soil absorption field (Venhuizen, 1995). This study was initiated to provide some information on processes that occur in the upper portion of the absorption field.

MATERIALS AND METHODS

For this study, data was collected on three low-pressure dosed, shallow, soil absorption fields associated with septic tanks utilizing recirculating sand filter treatment operating on Washington Island, Wisconsin (Figure 2). These systems were located at the Richter and Toyne residences and at the Mann Grocery Store. Data collected between August 1995, and July 1996, are reported.





Soil Classification

Soil samples for classification were obtained from the soil borings for the installation of lysimeters. When boring a hole for lysimeter installation, soil was removed in approximately 6 in. (15 cm) increments and segregated. In the field, these soil increments were evaluated to determine the general soil texture and color as depth of profile increased. Field analysis was performed by Dr. Ronald Stieglitz (Geologist). Sub-samples of these soil increments were then placed in plastic bags and transported to UW-Green Bay. In some cases, biased samples may have been collected. In some instances, large numbers of cobble stones were present and not included in the sample. This bias would result in an underestimate of the rock content.

To arrive at a soil texture, soil characteristics including particle-size, liquid limit,

plastic limit and plasticity index was done by utilizing the Unified Soil Classification System (USCS) according to ASTM Designation: D 2487-93: Classification of Soils for Engineering Purposes and D 4318-93: Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils (ASTM Standards, 1995).

Soil Microbiology

To obtain information on the distribution of fecal coliform in each of the three absorption fields, soil profiles directly beneath the distribution pipe within the absorption fields were sampled. In May 1996, three soil profiles were sampled at the Richter, Mann and Toyne sites. Two of the profiles sampled were beneath the absorption field. These soil profiles were located immediately below an existing dosing point in the effluent distribution system. Background levels of fecal coliform were determined on samples from soil profiles collected outside the absorption field impact zone.

Collection of soil began immediately below the gravel in the shallow distribution trench and continued at approximately 6 in. (15 cm) increments. Samples could not be taken at exact increments in the sites due to the rocky nature of the soils on Washington Island. Figure 3 shows a typical distribution trench and the location of sampling points. The 0 in. depth is at the gravel soil interface. Several grams of soil were collected in plastic tubes using sterile sampling techniques either by hand or with a soil sampler. After each collection, a 4 in. (9 cm) diameter hand auger was used to remove soil to the next depth. After each depth increment, the auger was cleaned and sterilized with a 10% bleach solution and rinsed with sterile distilled water to prevent sterilization of the next depth increment. Soil samples were stored at 4 C° until analysis. Analysis for fecal coliform was done in batches, beginning within 24 hours of sampling, with a maximum sample holding time of 96 hours .



Figure 3. Shallow Distribution Trench Showing Loaction of Sampling Points

Analysis for fecal coliform was performed at the University of Wisconsin-Green Bay. The most probable number (MPN) of fecal coliform was determined in each sample according to method 9221 E - Multiple Tube Fermentation Technique for Fecal Coliform (<u>Standard Methods for the Analysis of Water and Wastewater 18ed.</u>, 1992). Ten-fold dilutions beginning with 1 g mixed soil sample and 9 mL of a 0.1% sterile peptone solution were assayed. The MPN statistical analysis was used to estimate the concentration of indicator bacteria. Soil moisture content was determined on a dry basis by heating approximately 15 g of mixed soil 16-24 hours at 104°C. Moisture content was computed according to the equation:

Water content (Wt.-%) = [Moist weight - Oven dry weight]/Oven dry weight X100 (Hausenbuiller, 1985).

When fecal coliform are measured in unsaturated soils, as in this study, the data are reported as MPN/g of dry soil (Converse et al., 1991). Currently the MPN procedure is designed to enumerate the number of coliform per 100 mL of water volume. The

MPN/100 mL water is converted to MPN/g dry soil by using the soil moisture content on a dry basis. For example, given:

Wet weight of soil used in MPN procedure = 1.0 g

MPN result: 140 MPN/100 mL = 1.4 MPN/mL

Percent moisture = 14%

Dry fraction of sample = 1.00 - 0.14 = 0.86

MPN/g dry soil = (MPN/ml)/[(Wt. of wet soil)(Dry fraction)] = 1.4/[(1)(.86)]

= 1.6 MPN/g dry soil

Suction lysimeters were not used in the collection of fecal coliform samples because it was suspected that the fine porous structure of the collection cup and silica flour would retain the bacteria and prevent them from entering the porous sample cup of the lysimeter.

Vadose Zone Water Chemistry

To obtain information of the fate of Cl⁻, NH₄⁺-N, and NO₃⁻-N in these shallow soil absorption fields, analyses of water collected beneath the distribution lines were performed. Vadose zone water samples were collected through the use of Timco® Cup Type Lysimeters installed within the absorption field 12 to 26 in (30 cm to 66 cm) below the level of distribution pipe and mid way between the distribution laterals. Sampling at these locations was thought to be representative of the input to the groundwater aquifer.

Installation of suction lysimeters at the Richter and Mann sites took place in August 1995, and the Toyne site lysimeters were installed November 1995. These installations followed Timco® instruction with some modifications made for the shallow bedrock present on all three sites. The cup type lysimeter with an outside diameter of 2 in (5 cm) and length of 4 in (10 cm) were placed in boreholes of at least 4 in (10 cm) in diameter to allow for adequate silica slurry pack to surround the lysimeter. A garden shovel was first used to clear the turf from the surface, then a 4 in (10 cm) bucket hand auger was used to bore the soil. The depth of the bore holes were 26 to 40 in (65 to 100 cm) beneath the surface.

Table 1 shows depth of distribution pipe in the absorption fields for each site as well as depth of the lysimeters below the distribution pipe. During lysimeter installation large cobbles were often encountered and were removed by hand. If the rock could not be removed, and the depth of boring not sufficient to install lysimeter, the boring was back-filled and a new site for a boring was chosen. Larger diameter boreholes were dug when cobbles had to be removed; in these cases extra silica slurry pack was used.

Five lysimeters were installed at each site. Four were installed below the level of the distribution pipes within the absorption field at the midpoint between distribution points. One lysimeter was located out of the absorption field impact zone to obtain background data. All three absorption fields are low-pressure dosed into two or three zones, depending upon the particular system. Each zone is dosed one at a time and in sequence.

Water samples were collected from the lysimeters on a monthly basis for approximately one year, during the frost-free season (August-November 1995 and March-July 1996). To collect samples, lysimeters were first purged of any accumulated water and then vacuum was applied by a hand pump and maintained for ~30 minutes. Then, a representative sample was purged from the lysimeter cup. Two samples were taken from each lysimeter on each sampling date. The samples were collected in 30 mL Nalgene® bottles and kept cool until analyzed for Cl⁻, NH₄⁻-N and NO₃⁻-N. Analysis was performed at the University of Wisconsin-Green Bay by AutoAnalyzer® methods outlined in <u>Standard</u> <u>Methods for the Analysis of Water and Wastewater 18ed.</u>, 1992. The specific

Table 1:	Depth of	Distribution	Pipes	and	Lysimeters	s at R	lichter,	Mann	and
		Toyr	ne Site	s In I	nches				

RICHTER SITE				
	Depth From Surface (in)			
Distribution Pipe	14			
Background Lysimeter	37			
	Depth Below Distribution Line (in)			
Lysimeter 1	20			
Lysimeter 2	26			
Lysimeter 3	16			
Lysimeter 4	12			

MANN SITE				
	Depth from Surface (in)			
Distribution Pipe	17			
Background Lysimeter	. 19			
	Depth Below Distribution Line (in)			
Lysimeter 1	12			
Lysimeter 2	16			
Lysimeter 3	15			
Lysimeter 4	20			
	TOYNE SITE			
	Depth from surface (in)			
Distribution Pipe	13.5			
Background Lysimeter	29			
	Depth Below Distribution Line (in)			
Lysimeter 1	17.5			
Lysimeter 2	16.5			
Lysimeter 3	14.5			
Lysimeter 4	17.5			

methodologies are 4500-Cl⁻: Automated Ferricyanide Method, 4500-NH₃-N: Automated Phenate Method, 4500-NO₃ F: Automated Cadmium Reduction Method.

Statistical analysis, through the use of a paired t-test, was performed to determine if the two water samples from the same lysimeter on a given sampling date were of the same parent group and therefore, could be averaged. It was established that for each site, lysimeter and parameter, the two independent sampling results could be averaged.

Soil Chemistry

To obtain further data on the fate of N and Cl⁻ in the soil absorption system, soil profiles directly beneath the absorption field distribution pipe were sampled. In May 1996, three soil profiles were sampled from the Richter, Mann and Toyne sites. Two of the profiles sampled were within the absorption field. These soil profiles were located immediately below an existing dosing point. Background levels were determined on samples from a soil profile collected outside the absorption field impact zone.

Collection of soil samples began immediately beneath the gravel in the distribution system trench and then continued at approximately 6 in (15 cm) intervals. Samples could not be taken at exact increments throughout the site due to the rocky nature of the soil. Also, one sample was obtained immediately below the turf surface above distribution lines to determine if the soil cover was contaminated. Approximately 20 g of soil was collected in a Nalgene® flip-top container. Soil moisture content on a dry basis was determined at the University of Wisconsin-Green Bay.

Samples were prepared for chemical analysis per recommendations of the University of Wisconsin-Soil and Plant Analysis Lab, Madison, WI. Samples were air-

dried overnight, ground with mortar and pestle, passed through a No. 12 ASTM soil sieve, and packaged in plastic bags. Samples were analyzed for Cl^{-} , Total N, NO₃⁻-N and NH₄⁺-N.

RESULTS

The design, soil texture and time in service for each of the three OSWDS demonstration sites is unique and therefore, each will be discussed separately. Specific details on the advanced-design septic tank systems, as well as loading rates and effluent parameters are found in Williams 1995.

Richter System

Soil Characteristics

The Richter system was installed at the end of July 1992 and serves both a main house and a cottage (Figure 4). The general soil texture at the Richter site is coarse; by definition this means that more than 50 percent of the material is larger than 0.003 in. (0.08 mm). The Richter soil profiles, on average, display clean, poorly graded sand overlaying poorly graded sand with silt. (Table 1, Appendix A) Because of the sandy nature of the site, the soil has weak consistence and is generally without structure. The site is a level open field used as a horse pasture for two horses.

Fecal Coliform

The 1992-93 average fecal coliform levels for the Richter system effluent (input to absorption field) during the 12 month evaluation period was 1.4×10^4 counts/100 mL effluent, with monthly log averages ranging from 1.49×10^3 counts/100 mL to 1.29×10^5



Figure 4. Richter Soil Absorption Filed layout, Placement of Lysimeters and Location of

Soil Profiles

counts/100 mL (Williams, 1995). To our knowledge, there were no major changes in the use of this system between the two studies. Tables 2-4 give Richter moisture content and fecal coliform results.

Depth From Surface Inches	Moisture Content % dry basis	MPN/g dry soil
1-4	12	0
6-9	10	0
13-18	13	0
20-24	10	0
27-31	8	0

 Table 2: Fecal Coliform and Moisture Content in Richter Soil Background Profile

Table 3: Fecal Coliform and Moisture Content in Richter Soil Profile 1

Depth From Gravel Inches	Moisture Content % dry basis	MPN/g dry soil
0-3	19	6000
6-11	18	4
14-18	15	0
20-23	21	0

 Table 4: Fecal Coliform and Moisture Content in Richter Soil Profile 2

Depth From Gravel Inches	Moisture Content % dry basis	MPN/g dry soil
0-4	20	2900
8.5-10.5	18	2
15.5-18.5	12	0
22.5-24.5	14	9

Fecal coliform counts beneath the soil absorption system in Profile 1 decreased from 6.0×10^3 MPN/g dry soil in the 0-3 in (0-8 cm) depth below the gravel soil interface, to 0 MPN/g dry soil in the 14-18 in (36-46 cm) depth. Fecal coliform counts beneath the system in Profile 2 decreased from 2.9×10^3 MPN/g dry soil in the 0-4 in (0-10 cm) depth below the gravel soil interface to 9 MPN/g dry soil in the 22.5-24.5 in (57-62 cm) depth --a reduction of 99.9%. The background fecal coliform count for the Richter soil absorption system was 0 MPN/g dry soil in all depths of the profile.

Vadose Zone Water Chemistry

Monthly averages of NO₃⁻-N, NH₃-N and Cl⁻ for the five Richter lysimeters are found in Figures 5-9; Figure 10 shows the average response for the four lysimeters in the absorption field. Monthly NO₃⁻-N levels in the Richter soil absorption field lysimeters ranged from 0.0 to 10.9 mg/L, with a 9 month average of 2.7 mg/L and standard deviation of 3.3 mg/L (Table 1, Appendix B). With the exception of 10.5 and 10.9 mg/L, NO₃⁻-N levels from the August 1995 sampling, the NR 140 standard of 10 mg/L was met 8 months, while the standard was exceeded 1 month. Background lysimeter levels range from 0.0 to 5.9 mg/L with a 9 month average of 1.6 mg/L and standard deviation of 2.0 mg/L. From the 1992-93 study, monthly NO₃⁻-N levels for the Richter system effluent range from 6.1 to 43.1 mg/L, with a 12 month average of 12.5 mg/L (Williams, 1995).

The water chemistry results from lysimeter samples also found a significant range of responses between lysimeters sampled on the same date. This observation supports the need for 3 or 4 lysimeters per absorption field to acquire a more realistic average response, especially for NO₃⁻-N levels, which varied the most widely. Because Cl⁻ levels were found to be more consistent within the field, it is likely that denitrification rates varied within the absorption field.



Figure 5 Inorganic N and Chloride Levels in Richter Background Lysimeter



Figure 6 Inorganic N and Chloride Levels in Richter Lysimeter 1



Figure 7 Inorganic N and Chloride Levels in Richter Lysimeter 2



Figure 8 Inorganic N and Chloride Levels in Richter Lysimeter 3



Figure 9 Inorganic N and Chloride Levels in Richter Lysimeter 4





Monthly NH_3 -N levels in the Richter soil absorption field lysimeters ranged from 0.0 to 1.0 mg/L, with a 9 month average of 0.1 mg/L and standard deviation of 0.2 mg/L (Table 2, Appendix B). Background lysimeter levels ranged from 0.0 to 0.3 mg/L, with a 9 month average of 0.1 mg/L. The 1992-93 sand filter NH_3 -N levels ranged from 0.1 to 33.5 mg/L, with a 12 month average of 3.3 mg/L (Williams, 1995). This data suggests that ammonium is being sorbed to the soil or that is nitrified. Because the NH_3 -N levels are low entering the absorption field, it is not possible to determine if some of the NO_3 -N found in the lysimeters originated from nitrification of NH_3 -N in the absorption field.

Monthly Cl⁻ levels in the Richter soil absorption field lysimeter ranged from 0.0 to 74.7 mg/L, with a 9 month average of 27.1 mg/L and standard deviation of 27.6 mg/L (Table 3, Appendix B). Background lysimeter levels range from 0.0 to 35.6 mg/L, with a 9 month average of 9.8 mg/L and standard deviation of 14.1 mg/L.

Soil Chemistry

Tables 5-7 give the Richter soil analysis results. The data show that TN and NH₃-N levels in the Richter background profile are higher than levels found in profiles beneath the system throughout the profile. Furthermore, both Profile 1 and 2 show TN levels are ten times higher in samples immediately below the gravel soil interface than those 4-5 in (10-13 cm) below. It is assumed that particulate organic-N is being retained in the upper most section of the soil profile, even though a biomat was not readily apparent in these systems.

Ammonia-nitrogen levels in Profile 1 soils decreased from 1.3 mg/kg at the 0-3 in (0-7 cm) depth to 0.2 mg/kg at the 20-23 in (51-58 cm) depth. Because of the sandy soil

Depth Below	TN	NH₄-N	NO3-N	Cl	Moisture Content	NO₃-N in soil	Cl ⁻ in soil	NO₃-N:Cl⁻ ratio
Surface						moisture	moisture (Calcu-	in soil moisture
Inches	mg/kg	mg/kg	mg/kg	mg/kg	% dry basis	lated) mg/L	lated) mg/L	
1-4	2897	1.4	1.8	4.7	12	15	39	0.38
6-9	627	0.7	1.9	4.2	10	19	42	0.45
13-18	1114	2.1	2.9	4.4	13	22	34	0.66
20-24	494	4.1	2.3	5.3	10	23	53	0.43
27-31	309	2.0	2.5	5.6	8	31	70	0.45

Table 5: Levels of Nitrogen Compounds and Chloride in Richter Background Soil Profile

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Depth Below	TN	NH₄-N	NO₃-N	Cl	Moisture Content	NO₃-N in soil	Cl ⁻ in soil	NO₃-N:Cl⁻ ratio
Gravel						moisture (Calculated)	moisture (Calculated)	in soil moisture
Inches	mg/kg	mg/kg	mg/kg	mg/kg	% dry basis	mg/L	mg/L	
0-3	1610	1.3	33	17.4	19	174	92	1.9
6-11	162	0.2	3.5	12.7	18	19	70	0.28
14-18	67	1.8	3.8	11.8	15	25	79	0.32
20-23	71	0.2	3.9	9.4	21	18	44	0.41

Table 6: Levels of Nitrogen Compounds and Chloride Beneath Richter Soil Absorption Field - Profile 1

 Table 7: Levels of Nitrogen Compounds and Chloride Beneath Richter Soil Absorption Field - Profile 2

Depth Below Gravel	TN	NH₄-N	NO₃-N	Cŀ	Moisture Content	NO₃-N in soil moisture (Calculated)	Cl ⁻ in soil moisture (Calculated)	NO₃-N:Cl ⁻ ratio in soil moisture
Inches	mg/kg	mg/kg	mg/kg	mg/kg	% dry basis	mg/L	mg/L	
0-4	1258	0.4	15.7	24.9	20	78	124	0.63
8.5-10.5	124	0.3	3.6	14.5	18	20	80	0.25
15-19	86	0.2	2.9	8.9	12	24	74	0.33
22.5-25	35	0.5	2	16.1	14	14	115	0.12

in the Richter system, it is expected that this is in part due to nitrification. Profile 2 remains fairly constant at the low concentration of 0.4 to 0.5 mg/kg N throughout the profile.

Nitrate-nitrogen concentrations beneath the Richter system decrease with depth of profile. Converse et. al., 1991 made the point that if one assumes that all nitrate is associated with soil water and not with the soil particles, nitrate levels (mg/kg NO₃-N) in the soil can be converted to mg NO₃-N/L in the soil moisture by using the moisture content on a dry basis. The conversion from mg/kg of dry soil to mg/L of water is: mg/L = (Concentration in mg/kg)/(Fractional soil moisture content on dry basis). Making these calculations shows, the concentration of NO₃-N beneath the Richter system in Profile 1 decreased from 174 mg NO₃-N/L to 18 mg NO₃-N/L or a 90% reduction within 23 in (58 cm) of contact with soil. In Profile 2, the same calculation shows NO₃-N levels decreased from 78 mg NO₃-N/L (0-4 in.) to 14 mg NO₃-N/L (22.5-25 in) or a 82% reduction. Furthermore, the NO₃-N:Cl⁻ ratio decreases with depth of profile in both Profile 1 (1.90 to 0.41) and Profile 2 (0.63 to 0.12), while this ratio in the background profile is fairly constant (0.38 to 0.45). Both lines of evidence suggest that some denitrification occurs beneath the Richter system.

Mann System

Soil characteristics

This system was installed in July 1992 and serves Mann's grocery store (Figure 11). Restrooms used by customers and employees, a vegetable washing table, slop sinks used for cleaning and a butcher shop that processes meat contribute flow to this system.

Overall, the general soil texture at the Mann site is coarse; more than 50% of the soil is larger than 0.003 in. (0.08 mm). The average of the soil profiles display poorly graded sand with gravel overlaying silty-sand with gravel or silty-sand (Table 2, Appendix A).

Fecal Coliform

Average fecal coliform levels in the Mann Store system effluent during the 1992-93, 12 month evaluation period was 1.4×10^3 counts/100 mL, with monthly averages ranging from 5.9×10^1 counts/100 mL to 1.82×10^5 counts/100 mL(Williams, 1995). Again, there were no major changes in the use of this facility between the two studies as far as is known. Tables 8-10 give moisture content and fecal coliform results for the Mann site. Fecal coliform counts beneath the soil absorption system in Profile 1 decreased from 37 MPN/ g dry soil at the 0-3 in (0-7 cm) to 0 MPN/g dry soil in 14-16 in (36-41 cm). Fecal coliform counts beneath the system in Profile 2 decreased from 33 MPN/g dry soil in 1-11 in (2.5-28 cm) to 1 MPN/g dry soil in 12-14 in (30-36 cm) or a 97% reduction. The background fecal coliform count for the Mann site was 0 MPN/g dry soil in all depths of the profile.



Figure 11 Mann Soil Absorption Field Layout, Placement of Lysimeters and Location of

Soil Profiles

Depth From Surface Inches	Moisture Content % dry basis	MPN/g dry soil
2-4	17	0
6-9	12	0
15-17	2	0
21-23	5	0
27-29	3	0

 Table 8: Fecal Coliform and Moisture Content in Mann Background Soil Profile

 Table 9: Fecal Coliform and Moisture Content in Mann Soil Profile 1

Depth From Gravel Inches	Moisture Content % dry basis	MPN/g dry soil	
0-3	19	37	
6-10	9	1	
14-16	8	0	

Table 10: Fecal Coliform and Moisture Content in Mann Soil Profile 2

Depth From Gravel Inches	Moisture Content % dry basis	MPN/g dry soil
1-3	8	33
8-11	9	33
12-14	5	1

Vadose Zone Water Chemistry

Monthly averages of NO_3 -N, NH_3 -N and Cl⁻ for the five Mann lysimeters are found in Figures 12-16; Figure 17 is the average response for the four lysimeters in the absorption field. From these figures it can be seen that two of the four lysimeters displayed very high levels. It was difficult to obtain samples from two of the lysimeters



Figure 11 Inorganic N and Chloride Levels in Mann Background Lysimeter



Figure 12 Inorganic N and Chloride Levels in Mann Lysimeter 1



Figure 14 Inorganic N and Chloride Levels in Mann Lysimeter 2



Figure 15 Inorganic N and Chloride Levels in Mann Lysimeter 3



Figure 16 Inorganic N and Chloride Levels in Mann Lysimeter 4



Figure 17 Average Inorganic N and Chloride Levels in Mann Lysimeters

with low parameter levels. This could be due to the fact that the Mann site has large amounts of cobbles under the soil absorption field. These cobbles could possibly affect the volume of effluent available to these lysimeters by re-routing the effluent away from the lysimeter.

Monthly NO_3 -N levels in the Mann soil absorption field lysimeters ranged from 0.0 to 122 mg/L, with a 9 month average of 9.4 mg/L and standard deviation of 25.7 mg/L (Table 1, Appendix B). With the exception of 40.1 and 55.8 mg/L from the August 1995 sampling and 65.7 and 122.1 mg/L from the September 1995 sampling, NO_3 -N levels met the NR 140 standard of 10 mg/L NO_3 -N for 7 months, while the standard was exceeded 2 months. The NO_3 -N levels in the background lysimeter ranged from 0.0 to 2.6 mg/L with a 9 month average of 0.7 mg/L and standard deviation of 0.8 mg/L. Monthly NO_3 -N levels for the Mann Store system effluent ranged from 1.5 to 68.6 mg/L during the 192-93 study, with a 12 month average of 29.7 (Williams, 1995). From the Williams data, NO_3 -N pulses can be noted at various times throughout the study. These high levels of NO_3 -N may be due to activities in the grocery store i.e. meat processing. The Mann lysimeter data from August and September 1995 also show NO_3 -N pulses.

Monthly NH_3 -N levels in the Mann soil absorption field lysimeters range from 0.0 to 0.2 mg/L, with a 9 month average of 0.1 mg/L and standard deviation of 0.1 mg/L (Table 2, Appendix B). Background lysimeter levels range from 0.0 to 0.8 mg/L, with a 9 month average of 0.2 mg/L and standard deviation of 0.3 mg/L. During the 1992-93 study, sand filter NH_3 -N levels range from 1.4 to 46.0 mg/L, with a 12 month average of 6.5 mg/L (William, 1995).

Monthly Cl⁻ levels in the Mann soil absorption field lysimeters ranged from 0.0 to 141.5 mg/L with a 9 month average of 19.0 mg/L and standard deviation of 35.4 mg/L (Table 3, Appendix B). Background lysimeter levels ranged from 0.0 to 46.2 mg/L, with a 9 month average of 8.6 mg/L and standard deviation of 14.9 mg/L.

Soil Chemistry

Tables 11-13 give the Mann soil analysis results. Within the system, NH_3 -N levels are low and increase slightly in Profile 1 from 0.6 mg NH_3 -N/kg at 0-3 in. (0-8 cm) to 1.2 mg NH_3 -N/kg at 14-16 in. (35-41 cm). Profile 2 levels decrease from 0.8 mg NH_3 -N/kg at 1-3 in. (2.5-8 cm) to <0.1 mg NH_3 -N/kg at 12-14 in. (30-36 cm).

The NO₃-N levels in soil beneath the system decrease with depth. But, if it is assumed that NO₃-N is associated only with the soil water, NO₃-N levels in Profile 1 are 88 mg NO₃-N/L at 0-3 in (0-8 cm) and exit the profile at 89 mg NO₃-N/L in 14-16 in (36-41 cm). In Profile 2 levels decrease from the point of entry to the system [325 mg N/L at 1-3 in (2.5-8 cm)] toward the bottom of the profile [174 mg N/L at 12-14 in (30-36 cm)]. It should be noted that at the time of sampling, the soil moisture content of the Mann site was very low (Tables 11-13). These low moisture levels affect the calculated mg NO₃-N/L values in the soil moisture, because they are dependent upon soil moisture content. The lower the soil moisture content the higher the mg NO₃⁻-N/L.

A decrease in the NO_3 -N:Cl⁻ ratio in the soil moisture is evidence that denitrification is occurring. Profile 1 shows little evidence of denitrification since the ratio is essentially constant. The nitrate NO_3 -N:Cl⁻ ratio, however, decreases in Profile 2 indicating that some denitrification may be occurring.

Depth	TN	NH₄-N	NO₃-N	Cl	Moisture	NO ₃ -N	Cŀ	NO₃-N:Cl ⁻
Below			-		Content	in soil	in soil	ratio
Surface					Content	moisture	moisture	in soil
						(Calculated)	(Calculated)	moisture
Inches	mg/kg	mg/kg	mg/kg	mg/kg	% dry basis	mg/L	mg/L	
2-4	1785	2.0	1.4	5.6	17	8.2	33	0.25
6-9	714	2.6	1.6	8.3	12	13	69	0.19
15-17	128	0.2	0.6	4.7	2	30	235	0.13
21-23	91	0.2	1.6	5.9	5	32	118	0.27
27-29	77	0.1	1.1	5.7	3	36	190	0.19

Table 11: Levels of Nitrogen Compounds and Chloride in Mann Background Soil Profile

 Table 12: Levels of Nitrogen Compounds and Chloride Beneath Mann Soil Absorption Field - Profile 1

Depth	TN	NH₄-N	NO₃-N	Cl	Moisture	NO3-N	Cl	NO₃-N:Cl ⁻
Below					Content	in soil	in soil	ratio
Gravel						moisture	moisture	in soil
						(Calculated)	(Calculated)	moisture
Inches	mg/kg	mg/kg	mg/kg	mg/kg	% dry basis	mg/L	mg/L	
0-3	1479	0.6	16.8	39.6	19	88	208	0.42
6-10	443	0.8	5.9	20.1	9	66	223	0.29
14-16	409	1.2	7.1	14	8	89	175	0.51

Denth	TN	NH -N	NON	Cl	Moisture	NO₃-N	Cl	NO ₃ -N:Cl ⁻
Below		14114	110311		Content	in soil	in soil	ratio
Gravel						moisture	moisture	in soil
Claver						(Calculated)	(Calculated)	moisture
			malka	ma/ka	% dry basis	ma/l	ma/i	
Inches	mg/kg	mg/kg	mg/kg		70 01 y Dasis	l ing/L	1 119/2	
1-3	1394	0.8	26	25.2	8	325	315	1.03
8-11	224	0.5	11.8	18.9	9	131	210	0.62
12-14	290	<0.1	8.7	16.3	5	174	326	0.53

Table 13: Levels of Nitrogen Compounds and Chloride Beneath Mann Soil Absorption Field - Profile 2

Toyne System

This modified at-grade concept disposal field was installed in October 1996 and serves a family of five in the winter along with two 2-bedroom and two 1-bedroom commercial guest cabins in the summer (Figure 18). The Toyne system also employs a drip-irrigation field in the summer to accommodate the increase in effluent flow.

At the initiation of this study the Toyne system was in service for approximately one month. This fact is thought to contribute significantly to the erratic N levels found beneath the system. These erratic levels could be due to at least three factors. As shown in Williams (1995), new recirculating sand filter systems need 1 to 2 months to establish nitrifying bacteria. Thus, this soil absorption field was likely initially dosed with an NH₃-N rich effluent rather than a NO₃-N rich effluent. It is assumed that little opportunity for nitrification occurs in the soil absorption fields on Washington Island during the winter, due to the cold and snow covered conditions. Also, on the March 1996 sampling date, it was noted at time of purging, that the lysimeter was full of water. This indicates that the lysimeters likely were in the saturated zone and water had infiltrated into the lysimeters. Because saturated conditions are not conducive to nitrification, high levels of NH₃ -N would remain in the absorption field. Another factor affecting the N levels, could be the fact that the Toyne system was constructed in the fall months on a site that was previously occupied by trees with a significant O horizon. This zone was disturbed at installation per recommendations for at-grade systems and would have incorporated some organic material into the lower soil layers. Also, when installing lysimeters and collecting soil profile decaying vegetation was observed in soil profiles. This may contribute to the high NH₃-N levels measured. A May 1996 NH₃-N value for Toyne sand filter effluent found 0.35 mg NH₃-N/L, indicating that the sand filter had established a culture of nitrifying bacteria and is was functioning as expected.



Figure 18 Toyne Soil Absorption Field Layout, Placement of Lysimeters and Location of

Soil Profiles

Soil characteristics

Overall, the general soil texture in the Toyne site is coarse, more than 50% of the material is larger than 0.003 in. (0.08 mm). The average of the soil profiles display poorly graded sand with silt overlaying silty sand and silty sand with gravel (Table 3 Appendix A).

Fecal Coliform

A grab sample from the Toyne sand filter collected in May 1996 had a low fecal coliform count of 2 MPN/100 mL of effluent indicating that the sand filter was efficiently removing bacteria at that time. Tables 14-16 give Toyne moisture content and fecal coliform results in the soil absorption field profiles. Fecal coliform counts beneath the soil absorption system in Profile 1 fluctuated between 2 and 3 MPN/g dry soil throughout the depth of the profile. Fecal coliform counts beneath the system in Profile 2 increased from 5 MPN/g dry soil at the 0-2 in (0-5 cm) depth below the gravel soil interface to 11 MPN/g dry soil at the 12-15 in (30-38 cm) depth. The fact that low levels of fecal coliforms were found through the entire soil column may be due to the fact that samples were taken from recently disturbed soils that may have had some residual coliforms present. Also, open channels and pores in this disturbed soil may have remained and aided in the distribution of coliform throughout the profile. It is assumed that in time the soil of this new absorption field will settle and compact, increasing the filtering capability. The background fecal coliform count for the Toyne site was 0 MPN/g dry soil in all depths of the profile.

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Depth From Surface Inches	Moisture Content % dry basis	MPN/g dry soil
2-4	49	0
8-14	22	0
14-17	9.4	0
22-26	11	0
30-32	8	0

Table 14: Fecal Coliform and Moisture Content in Toyne Background Profile

 Table 15
 Fecal Coliform and Moisture Content in Toyne Soil Profile 1

Depth From Gravel Inches	Moisture Content % dry basis	MPN/g dry soil
3-5	16	3
5-9	19	2
9-12	61	3
12-14	24	2

 Table 16: Fecal Coliform and Moisture Content in Toyne Soil Profile 2

Depth From Gravel Inches	Moisture Content % dry basis	MPN/g dry soil
0-2	45	5
7-10	67	33
12-15	100	11

Vadose Zone Water Chemistry

Monthly averages of NO_3^-N , NH_3^-N and CI^- for the five Toyne lysimeters are found in Figures 19-23. Figure 24 is the average response for the four lysimeters in the -----



Figure 19 Inorganic N and Chloride Levels in Toyne Background Lysimeter



Figure 20 Inorganic N and Chloride Levels in Toyne Lysimeter 1



Figure 21 Inorganic N and Chloride Levels in Toyne Lysimeter 2



Figure 22 Inorganic N and Chloride Levels in Toyne Lysimeter 3



Figure 23 Inorganic N and Chloride Levels in Toyne Lysimeter 4



Figure 24 Average Inorganic N and Chloride Levels in Toyne Lysimeters

absorption field. Monthly NO₃⁻-N levels for Toyne soil absorption field lysimeters ranged from 0.0 to 12.5 mg/L, with a 6 month average of 1.6 mg/L and standard deviation of 3.4 mg/L. With the exception of 11.6 and 12.5 mg/L from the March 1996 sampling, NO₃⁻-N levels met the NR 140 standard of 10 mg NO₃⁻-N/L for 5 months, while the standard was exceeded 1 month. Background lysimeter levels ranged from 0.0 to 4.7 mg NO₃⁻-N/L with a 6 month average of 1.0 mg NO₃⁻-N/L and standard deviation of 1.8 mg NO₃⁻-N/L. The value for a grab sample collected in May 1996, from the sand filter at the Toyne site, was 26.6 mg NO₃⁻-N/L (Table 1, Appendix A).

Monthly NH_3 -N levels in the Toyne soil absorption field lysimeters ranged from 0.0 to 22.8 mg NH_3 -N/L, with a 6 month average of 6.2 mg NH_3 -N/L and standard deviation of 6.3 mg NH_3 -N/L. Background lysimeter NH_3 -N levels ranged from 0.0 to 0.9 mg/L, with a 6 month average of 0.3 mg/L and standard deviation of 0.4 mg/L. The value for a grab sample collected in May 1996, from the sand filter at the Toyne site was 0.35 mg/L (Table 2, Appendix B).

Monthly Cl⁻ levels from lysimeters inside the Toyne soil absorption field ranged from 16.2 to 31.2 mg/L, with a 6 month average of 23.6 mg/L and standard deviation of 4.2 mg/L. Background levels in lysimeters outside the Toyne absorption field ranged from 2.2 to 9.1 mg/L, with a 6 month average of 4.5 mg/L and standard deviation of 2.9 mg/L. The Cl⁻ value for a grab sample collected in May 1996, from the sand filter at the Toyne site was 24.9 mg/L (Table 3, Appendix B).

Soil Chemistry

Tables 17-19 give the Toyne soil analysis results. Ammonia-nitrogen and TN levels beneath the Toyne system far exceeds background levels at all depths. Ammonianitrogen levels fluctuate in Profile 1, the top most portion of the soil column below the

Depth	TN	NH₄-N	NO₃-N	Cl	Moisture	NO ₃ -N	Cl	NO ₃ -N:Cl ⁻
Below			÷		Content	in soil	in soil	ratio
Surface						moisture	moisture	in soil moisture
						(Calculated)	(Calculated)	
Inches	mg/kg	mg/kg	mg/kg	mg/kg	% dry basis	mg/L	mg/L	
2-4	396	1.3	13.6	3.9	49	28	8	3.49
8-14	3020	0.2	12.8	6.7	22	58	30	1.91
14-17	297	0.9	0.8	6.5	9.4	8	69	0.012
22-26	317	0.3	1.3	6.5	11	12	59	0.20
30-32	57	0.1	0	9	8	0	112	NA

Table 17: Levels of Nitrogen Compounds and Chloride in Toyne Background Soil Profile

Depth Below Gravel	TN	NH₄-N	NO₃-N	Cl	Moisture Content	NO₃-N in soil moisture (Calculated)	Cl ⁻ in soil moisture (Calculated)	NO₃-N:Cl ⁻ ratio in soil moisture
Inches	mg/kg	mg/kg	mg/kg	mg/kg	% dry basis	mg/L	mg/L	
3-5	5084	0.7	73.9	13	16	461	81	5.68
5-9	154	15.7	1.5	11.9	19	8	62	0.13
9-12	3248	0.7	32.4	13.7	61	53	22	2.36
12-14	3169	4.4	25.7	0.1	24	107	0.4	257

 Table 18: Levels of Nitrogen Compounds and Chloride Beneath Toyne Soil Absorption Field - Profile 1

 Table 19: Levels of N and Cl⁻ Beneath Toyne Soil Absorption Field- Profile 2

Depth Below	TN	NH₄-N	NO ₃ -N	Cl	Moisture Content	NO₃-N in soil	Cl ⁻ in soil	NO₃-N:Cl ⁻ ratio
Gravel						moisture (Calculated)	moisture (Calculated)	in soil moisture
Inches	mg/kg	mg/kg	mg/kg	mg/kg	% dry basis	mg/L	mg/L	
0-2	4698	23.6	5.5	19.1	45	12	42	0.29
7-10	5378	28.4	2.5	13	67	3	19	0.19
12-15	4220	0.7	28.5	3.2	100	28.5	3.2	8.91

absorption system had 0.7 mg/kg at 3-5 in. (8-13 cm) while the deepest sample had 4.4 mg/kg at 12-14 in. (30-36 cm). Profile 2 displays higher NH_3 -N levels in the shallow samples with 23.6 mg/kg at 0-2 in. (0-5 cm), but levels decreased to 0.7 mg/kg at 12-15 in. (30-38 cm) at the bottom of the profile.

The calculated NO_3 -N levels in the soil moisture are erratic throughout the Toyne site. The initial NO_3 -N concentration beneath the gravel soil interface in Profile 1 is 461 mg NO_3 -N/L at 3-5 in. (8-13 cm) and decreases to 107 mg NO_3 -N/L at 12-14 in. (30-36 cm). The NO_3 -N:Cl⁻ ratio does suggest denitrification to this point, but it does not continue throughout profile. It is difficult to speculate on the mechanisms of nitrogen compound removal because of the highly varied soils and forms of nitrogen applied to the system in the first six to eight months of operation in this absorption field.

DISCUSSION

The soils at the three test sites on Washington Island are defined as coarse textured by the Unified Soil Classification System. The surface material at the Richter site is poorly graded sand changing to poorly graded sand with silt lower in the profile. The Mann and Toyne sites are similar with surface material being poorly graded sand with silt and changing to silty sand with gravel. While the Mann and Toyne sites had a greater amount of fines, they also had a greater amount of gravel and rock fragments.

At all three sites, fecal coliform counts in background profiles were below detection levels. Both profiles in the Richter system achieved 99.9-100% reduction of fecal coliforms within 25 in (83 cm) below the gravel soil interface. In the Mann system, 97% fecal coliform reduction occurred within a 16 in. (41 cm) soil column (Profile 1). A count of 1 MPN/g dry soil was found at the base of the profile. In Profile 2, 100% reduction occurred within 14-16 in. (36-41 cm). Fecal coliform counts at the Toyne site fluctuated between 5 to 11 MPN/g dry soil throughout the soil profile. This may be due to the fact that this was a new site where the top soil had been disrupted and the soil may not have had sufficient time to settle, and therefore reduce the size of pores in the soil. This would result in channeling of the effluent through the soil. As a consequence coliforms were found throughout the soil profile. As well, there may be slower reduction at this site due to the presence of organic material and higher moisture contents throughout the profiles, both conditions favor bacterial survival.

Seasonal changes in NH_3 -N and NO_3 -N concentrations are expected, especially in systems on Washington Island where the systems were snow covered for 6 months followed by saturation with snowmelt. Nitrification is slowed when saturated, cool conditions of the winter months exist, and it is enhanced when the soils become warm and unsaturated during the summer. Reneau (1979) noted, that the increase in NO_3 -N in

the groundwater was actually greatest as the water table rose in the fall, dissolving NO_3^- -N which was formed during the summer. This phenomena appears to be occurring at the sites in the Washington Island study.

While data from the soil chemistry study is useful in indicating if denitrification is taking place, which appears to be occurring beneath the Richter and Mann sites, it is impossible to calculate the average soil nitrate concentration beneath the system. The profiles being evaluated are probably the worst case scenario, as they are receiving the highest concentration of effluent, and therefore, do not represent the entire area beneath the system. To gain further insight a comparison of this study to similar soil absorption field studies is made.

In the state of Wisconsin there have been other studies regarding OSWDS developed for difficult sites, usually due to failure to meet minimum separation distance for conventional soil absorption fields or "poor" soils. One study evaluated nitrogen and fecal coliform removal in Wisconsin mound systems (Converse, et al., 1994) while the other evaluated bacterial and nutrient removal in Wisconsin at-grade systems (Converse, et al., 1991) This study on Washington Island evaluated nitrogen and fecal coliform removal in shallow, low-pressure dosed soil absorption fields following treatment in advanced design septic tanks. These three studies can be compared because of the similarity in sampling and analysis procedures (the same soil analysis laboratory was used), as well as in the location of samples beneath the fields. In all three studies, fecal coliform and soil nitrogen samples were collected beneath the sandfill (gravel) soil interface in the distribution trench directly below a dosing point. In addition, all three studies examined systems that are pressure dosed. In retrospect, the Toyne data is not a good comparison for reasons stated earlier.

Table 20 displays nitrogen and fecal coliform concentrations at the base of two

profiles at each site in this study, as well as concentrations of parameters at the bottom of profiles in a mound and an at-grade study. This table gives evidence that there is benefit to applying sand filter effluent to a soil absorption field in comparison to conventional septic tank effluent. It should be noted that the depth of profiles are deeper in the mound and at-grade studies, allowing for longer soil-effluent contact.

While the data set is limited for this study, this table shows that when parameters are compared between the three disposal field designs, the fecal coliform counts for all sites in this study are below the levels found in the mound and at-grade systems. Apparently, the lower levels of coliforms in the effluent applied to the Washington Island

systems limits depth of penetration.

System	Depth of Profile Inches	Fecal Coliform MPN/g dry soil	Nitrate- Nitrogen mg/kg dry soil	Ammonium- Nitrogen mg/kg dry soil	Total Nitrogen mg/kg dry soil
Shallow,	R=25, 23	R= 9, 0	R= 3.9, 2	R= 0.2, 0.5	R= 71, 35
LPD*	M=16, 14	M= 1, 0	M= 7.1, 8.7	M= 4.4, 0.7	M= 409, 290
	T=14, 15	T= 2,11	T= 26, 29	T= 1.2, <0.1	T= 3169, 4220
Mound **	23	103	7	10	749
At-grade ***	42	193	9	17	400

Table 20: Comparisons of Parameters at the Base of Soil Profiles Beneath Absorption

 Fields

R=Richter site, M= Mann site, T= Toyne site

*Soil profile parameters for three shallow, low-pressure dosed systems following treatment in a recirculating sand filter septic system.

**Average soil profile parameters for 13 septic tank/mound units using pressure distribution on similar soil profiles (Converse et. al., 1994).

***Average soil profile parameters for 28 septic tank/at-grade units using pressure distribution on similar soil profiles.(Converse et. al., 1991).

The NO₃-N levels at the base of the Richter profiles (3.9 and 2 mg NO₃-N/kg) are below levels at the Mann profiles (7.1 and 8.7 mg NO₃-N/kg) the mound (7 mg NO₃-N/kg) and at-grade (9 mg NO₃-N/kg) systems. The data also indicates that the range of NH₃-N levels at sites in this study are minimal (<0.1 and 4.4 mg NH₃-N/kg), compared to 10 and 17 mg NH₃-N/kg in the mound and at-grade studies. This is a substantial amount of NH₃-N that can be converted to NO₃-N.

This data indicates that the demonstration systems on Washington Island provide substantially better fecal coliform reduction within a shorter distance than the mound and at-grade systems depicted in the Converse et al. studies. This data also shows that the Richter site has more effective N removal than the Mann site, mound and at-grade systems.

CONCLUSIONS

Based on nine months of data collection from three soil absorption fields receiving wastewater from septic tank systems using recirculating sand filters on Washington Island, WI, the following conclusions are made.

1. Fecal coliform bacteria applied to shallow, low-pressure dosed fields on Washington Island approach zero after passing through 2 feet of soil beneath the dosing point. This short retention distance may be a consequence of the fact that fecal coliform levels from recirculating sand filter systems are lower than levels in conventional septic tank effluent.

2. Ammonia-nitrogen levels in the soil absorption fields studied receiving effluent from recirculating sand filter systems compared to those receiving conventional septic are approximately an order of magnitude lower. Furthermore, ammonia-nitrogen levels in soils 14 to 25 inches beneath the distribution trench are only a few mg/kg. These soils, therefore, represent only a small reservoir of ammonia-nitrogen that can be nitrified to nitrate-nitrogen.

3. Levels of nitrate-nitrogen in the soil profiles below absorption trenches decrease with depth. In addition, the nitrate-nitrogen to chloride ratios decreased with depth in the soil profile in two of the systems. Both lines of evidence suggest that some denitrification takes place within the soil immediately below the absorption fields.

4. Recirculating sand filter effluent has the apparent advantage that nearly all the inorganic nitrogen is in the form of nitrate when applied to the absorption field and thus it is in the form that can be denitrified even further.

5. Water collected from the vadose zone of the absorption fields over 9 months, through the use of lysimeters, yielded levels which ranged between 0.0 to 10.9 mg/L NO₃⁻-N and 0.0 to 0.6 mg/L NH₃-N at the residential site, 0.0 to 122.1 mg/L NO₃⁻-N and 0.0 to 0.8 mg/L NH₃-N at a commercial grocery site and 0.0 to 12.5 mg/L NO₃⁻-N and 0.0 to 22.8 mg/L NH₃-N at the newly installed residential site. The reason for the high nitrate levels intercepted by two of four lysimeters at the grocery store is believed to be related to meat processing activities in the store. It is also possible that the capillary fringe may have risen to the zone sampled by two of the lysimeters during the heavy use months at the store site. As the capillary fringe rises it may dissolve nitrate retained by dry soil.

6. The inorganic nitrogen chemistry for the newly-installed system was difficult to interpret because it likely received effluent both before and after the sand filter developed an active culture of nitrifying bacteria.

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APPENDIX A

Sample	Depth From Surface Inches	Unified Classification	Description
Richter Background Boring	0-5	SP	Olive-grey, poorly graded sand
	5-10	SP	Lt. grey, poorly graded sand
	10-15	SP	Lt. grey, poorly graded sand
	15-20	SP	Lt. grey, poorly graded sand
	20-25	SP-SM	Lt. grey, poorly graded sand with silt
	25-30	SP-SM	Yellowish-orange, poorly graded sand with silt
	30-35	SW-SC	Lt. brown, well graded sand with clay and gravel
	35-40	SW-SC	Lt. brown, well graded sand with clay and gravel
Richter Boring 1	0-6	SP	Olive-grey, poorly graded sand
	6-12	SP	Olive-grey, poorly graded sand
	12-18	SP	Olive-grey, poorly graded sand
	18-24	SP-SM	Yellowish-orange, poorly graded sand with silt
	24-30	SP-SM	Yellowish-orange, poorly graded sand with silt
	30-36	SP-SM	Yellowish-orange, poorly graded sand with silt
Richter Boring 2	0-6	SP	Olive-grey, poorly graded sand with silt
	6-12	SP-SM	Dk. grey, poorly graded sand with silt

Table 1: Richter Soil Classification

Richter Boring 2	12-18	SP-SM	Dk. grey, poorly graded sand with silt
	18-24	SP-SM	Yellowish-orange, poorly graded sand with silt
	24-30	SP-SM	Yellowish-orange, poorly graded sand with silt
	30-36	SP-SM	Yellowish-orange, poorly graded sand with silt
	36-42	SP	Yellowish-orange, poorly graded sand with silt
Richter Boring 3	0-6	SP	Dk. grey, poorly graded sand
	6-12	SP	Dk. grey, poorly graded sand
	12-18	SP	Dk. grey, poorly graded sand
	18-24	SP-SM	Lt. brown, poorly graded sand with silt
	24-31	SP-SM	Lt. brown, poorly graded sand with silt
Richter Boring 4	0-5	SP-SM	Olive-grey, poorly graded sand with silt
	5-10	SP	Olive-grey, poorly graded sand
	10-15	SP	Olive-grey, poorly graded sand
	15-20	SP-SM	Olive-grey, poorly graded sand with silt
	20-26	SW	Yellowish-orange, well graded sand

T	able	2:	Mann	Soil	Classification

Sample	Depth From Surface Inches	Unified Classification	Description
Mann Background Sample	0-4	SP-SM	Olive-grey, poorly graded sand with silt
	4-10	SP-SM	Lt. brown, poorly graded sand with silt
	10-16	SP-SM	Lt. brown, poorly graded sand with silt
	16-22	SM	Lt. brown, silty sand with gravel
Mann Boring 1	0-6	SP	Yellowish-orange, poorly graded sand with gravel
	6-12	SP	Yellowish-orange, poorly graded sand with gravel
	12-18	SP-SM	Lt. brown, poorly graded sand with silt
	18-24	SP-SM	Lt. brown, poorly graded sand with silt and gravel
	24-30	SP-SM	Lt. brown, poorly graded sand with silt and gravel
Mann Boring 2	0-7	GW	Olive-grey, well graded gravel with sand
	7-14	SM	Lt. brown, silty sand with gravel
	14-21	SM	Lt. brown, silty sand
	21-28	SM	Lt. brown, silty sand
	28-35	SP-SM	Yellowish-orange, poorly graded sand with silt and gravel
Mann Boring 3	0-7	SP-SM	Lt. brown, poorly graded sand with silt and gravel
	7-14	SM	Lt. brown, silty sand
	14-21	SM	Yellowish-orange, silty sand
	21-28	SM	Yellowish-orange, silty sand

Mann Boring 3	28-35	SM	Yellowish-orange, silty sand
Mann Boring 4	0-6	SP-SM	Olive-grey, poorly graded sand with silt and gravel
	6-12	SM	Olive-grey, silty sand with gravel
	12-18	SM-SM	Yellowish-orange, poorly graded sand with silt and gravel
	18-24	SM	Yellowish-orange, silty sand with gravel
	24-30	SM	Yellowish-orange, silty sand with gravel
	30-40	SM	Yellowish-orange, silty sand with gravel

Table 3: Toyne Soil Classification

Sample	Depth From Surface Inches	Unified Classification	Description
Toyne Background Sample	0-6	SP-SM	Dk. grey, poorly graded sand with silt and gravel
	6-8	SM	Olive-grey, silty sand with gravel
	8-14	SM	Olive-grey, silty sand with gravel
	14-20	SM	Lt. grey, silty sand with gravel
	20-25	SM	Lt. grey, silty sand with gravel
	25-28	SM	Lt. grey, silty sand with gravel
	28-32	SM	Lt. grey, silty sand with gravel
Toyne Boring 1	0-5	SP-SM	Yellowish-orange, poorly graded sand with silt
	. 5-10	SP-SM	Yellowish-orange, poorly graded sand with silt
	10-15	SM	Olive-grey, silty sand
	15-20	SP-SM	Olive-grey, poorly graded sand with silt
	20-25	SM	Lt. grey, silty sand with gravel
	25-30	SM	Lt. grey, silty sand with gravel
Toyne Boring 2	0-5	SP-SM	Yellowish-orange, poorly graded sand with silt
	5-10	SP-SM	Yellowish-orange, poorly graded sand with silt
	10-15	SM	Dk. grey, silty sand
	15-20	SM	Olive-grey, silty sand with gravel
	25-30	SM	Olive-grey, silty sand with gravel

Toyne Boring 2	30-33	SM	Lt. grey, silty sand with gravel
Toyne Boring 3	0-6	SP-SM	Yellowish-orange, poorly graded sand with silt
	6-12	SP-SM	Yellowish-orange, poorly graded sand with silt
	12-18	SP-SM	Olive-grey, poorly graded sand with silt
	18-30	SP	Olive-grey, poorly graded sand
Toyne Boring 4	0-6	SP-SM	Yellowish-orange, poorly graded sand with silt
	6-12	SP-SM	Yellowish-orange, poorly graded sand with silt
	12-18	SP-SM	Olive-grey, poorly graded sand with silt
	18-24	SP-SM	Olive-grey, poorly graded sand with silt and gravel
	24-30	SM	Olive-grey, silty sand with gravel
	30-35	SM	Olive-grey, silty sand with gravel

APPENDIX B

Site	8-31-95	9-28-95	11-4-95	3-31-96	4-1-96	4-27-96	5-29-96	6-25-96	7-28-96
Richter Bkgd Lysimeter	2.9	5.9	2.9	0.4	1.2	1.0	0.3	0.0	0.0
Lysimeter 1	2.6	3.6	2.4	2.2	2.7	3.3	1.2	0.0	0.0
Lysimeter 2	10.5	8.0	0.1	7.5	6.9	0.9	0.0	0.0	0.0
Lysimeter 3	10.9	2.2	0.0	8.0	8.3	1.4	0.0	0.0	0.0
Lysimeter 4	1.8	0.3	0.1	4.5	5.1	3.5	0.1	0.0	0.0
Mann Bkgd Lysimeter	0.7	2.6	0.3	0.7	1.1	0.9	0.0	0.0	0.0
Lysimeter 1	40.1	65.7	0.5	2.6	3.3	0.7	0.0	0.0	0.7
Lysimeter 2	NS	2.7	0.2	0.5	0.6	0.4	0.0	0.0	0.0
Lysimeter 3	NS	NS	0.1	0.0	0.4	0.2	0.0	0.0	0.0
Lysimeter 4	55.8	122.1	0.5	0.0	0.4	12.0	0.0	0.0	0.0
Toyne Bkgd Lysimeter				0.5	0.0	0.5	0.0	0.0	4.7
Lysimeter 1	1			0.0	0.8	0.4	1.1	0.0	0.0
Lysimeter 2	1			11.6	0.4	0.4	0.0	0.0	0.0
Lysimeter 3	1			12.5	0.4	3.3	0.0	0.2	0.0
Lysimeter 4	1			3.4	3.1	0.5	0.0	0.0	0.0

Tabla	1. Monthly	Averane	NO.	-N Water	Chemistry	leve	s in ma N/L
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NS=No sample obtained from lysimeter

Site	8-31-95	9-28-95	11-4-95	3-31-96	4-1-96	4-27-96	5-29-96	6-25-96	7-28-96
Richter Background Lysimeter	0.0	0.3	0.3	0.0	0.0	0.0	0.0	0.1	0.0
Lysimeter 1	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Lysimeter 2	0.3	0.2	0.2	0.1	0.0	0.1	0.1	1.0	0.0
Lysimeter 3	0.6	0.1	0.4	0.0	0.0	0.0	0.0	0.1	0.1
Lysimeter 4	0.2	0.1	0.1	NS	0.2	0.0	0.1	0.0	0.0
Mann Bkgd Lysimeter	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.3	0.8
Lysimeter 1	0.3	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Lysimeter 2	NS	0.1	0.1	0.0	0.0	0.1	0.0	0.1	0.2
Lysimeter 3	NS	NS	0.1	0.0	0.0	0.1	0.0	0.1	0.1
Lysimeter 4	0.3	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.1
Toyne Background Lysimeter		A		0.0	0.0	0.0	0.0	0.7	0.9
Lysimeter 1	1			0.2	0.3	0.0	0.5	1.1	1.8
Lysimeter 2]			0.6	1.0	2.3	3.3	8.0	12.1
Lysimeter 3]			22.8	21.7	11.4	8.0	5.8	4.9
Lysimeter 4				13.5	6.4	3.9	3.5	7.0	8.1

Table 2: Monthly Average NH₃-N Water Chemistry Levels in mg N/L

NS=No sample obtained from lysimeter





172856 Evaluation of Shallow Soil Absorption Fields...

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Site/Date	8-31-95	9-28-95	11-4-95	3-31-96	4-1-96	4-27-96	5-29-96	6-25-96	7-28-96
Richter Bkg Lysimeter	35.6	30.5	15.7	2.0	1.3	1.0	0.3	0.0	1.5
Lysimeter 1	67.3	79.2	23.3	11.4	10.4	3.9	1.3	0.0	10.0
Lysimeter 2	71.5	81.3	22.6	14.9	13.0	3.6	1.3	2.7	29.5
Lysimeter 3	54.7	73.0	30.0	19.8	19.5	3.6	1.3	1.3	19.3
Lysimeter 4	74.7	85.5	44.3	20.8	20.8	5.2	3.0	12.1	39.3
Mann Bkg Lysimeter	46.2	11.5	12.6	0.7	0.7	0.0	0.7	0.0	4.8
Lysimeter 1	52.6	109	4.3	1.3	1.3	2.0	0.7	0.0	65.0
Lysimeter 2	NS	26.2	1.7	0.7	0.0	1.6	1.3	0.0	2.2
Lysimeter 3	NS	NS	1.6	0.0	0.0	2.0	1.3	0.0	5.9
Lysimeter 4	97.4	141	35.6	3.9	4.6	14.6	10.5	4.4	32.7
Toyne Bkg Lysimeter		<u> </u>		9.1	7.5	4.9	3.3	3.4	2.2
Lysimeter 1				19.5	23.4	29.2	27.5	28.2	31.2
Lysimeter 2	1			29.5	28.6	25.3	19.7	19.5	23.8
Lysimeter 3	1			21.1	22.7	16.2	18.4	18.1	22.3
Lysimeter 4				27.8	26.9	24.7	21.0	19.5	23.8

Table 3: Monthly Average CI Water Chemistry Levels in mg/L

NS=No sample obtained from lysimeter.

