ABSTRACT

Effects of Recharge Events below On-Site Wastewater
Drain Fields as Related to Soil Type

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This study evaluated septic effluent as it was affected by recharge through different soil types. The methodology included a column study involving three soil classifications (types); Type Ib soils (sands and loamy sands), Type II soils (sandy loams and loams) and Type III soils (sandy clay loams). Loading rates followed ANSI/NSF Standard 40 design loading and local regulations for wastewater volume allowed per drain field area per soil type. All soil types effectively removed CBOD (>85% reduction). The soils were less effective at removing TSS with removal rates ranging from 52% to 87%. Total inorganic nitrogen (TIN) removal efficiency for Type Ib soils was only 10% while Type III soils removed 66% of TIN. A 5-year, two-hour storm diluted the effluent leaving the soil by decreasing concentrations without increasing mass flux. The larger recharge events appeared to flush the columns and increased the mass flux of contaminants below the soil.

Effects of Recharge Events below On-Site Wastewater
Drain Fields as Related to Soil Type

by

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A Thesis

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CHAPTER ONE

Introduction

Background / Problem Statement

Much of Texas and the United States treat their wastewater with “on-site” sewage facilities (OSSFs). One estimate puts the number of OSSFs in the Unites States at over 22 million systems, serving 25% of the population (Conn and others, 2006). These OSSFs are designed traditionally as “septic” tanks with absorption systems termed “leach fields” where wastewater is introduced into the soil and may eventually percolate into groundwater (Rainwater, 2004). Wastewater contamination is a recognized problem worldwide. In addition to increasing the carbonaceous biochemical oxygen demand (CBOD), total suspended solids (TSS) and adding nitrogen to groundwater, recent studies have shown that emerging contaminants (ECs) are frequently being discovered in groundwater as a result of wastewater dispersal (Giger and others, 2003, Barnes and others, 2004, Petrovic and others, 2004, Verstraeten and others, 2005, Conn and others 2006 and Godfrey and others 2007).

Currently the Texas Commission on Environmental Quality (TCEQ) codes are written such that septic effluent may not be discharged into soil within two feet of the seasonally high water table or any hydraulic barrier, such as the water table or an impermeable layer. (30 TAC, Chapter 285). Although the leach field is considered part of the onsite treatment system and is expected to improve the effluent quality before it reaches the groundwater, current regulations consider soil type (texture) primarily for sizing the leach field to expected volumes rather than to produce a specific quality of effluent. The size of the leach field is therefore designed based on soils infiltration rates and wastewater volume to prevent surface ponding or backing-up of effluent into the house. This approach addresses the wastewater but does not address contamination possibilities as related to soil types. Soil can ameliorate the treated effluent through various physical, chemical and biological processes that occur as the fluid percolates through the vadose zone and approaches groundwater and therefore affects effluent quality (Dawes and Goonetilleke, 2003 and Conn and others, 2006).

Although little is known about the specific effects of soil type on septic effluent quality, even less is known about the effects of recharge on effluent quality. Soil texture affects rates of infiltration and the amounts of water moving through the vadose zone which could affect effluent quality both in terms of contaminant concentration and mass. Previous researchers have examined surface sewage/sludge application using intact soil columns (Dawes and Goonetilleke, 2006), disturbed soil columns (John, 1974 and Veneman and others, 2002) and intact soil lysimeters (McLaren and others, 2003). Others have evaluated differences in leach field trench/soil interface media using soil columns (Siegrist and others, 2004) and using lysimeters (Van Cuyk and others, 2001). However no one has approached this problem by specifically examining leach field contaminant removal with the use of dosing frequencies and volumes as well as recharge events, so representative of "real world" conditions.

Purpose

The focus of the study is the effect of soil type on septic effluent treatment in soil and subsequently the potential for recharge events to affect the movement of effluent through the vadose zone and into groundwater. Specifically this study determined the change in amount of Total Inorganic Nitrogen (TIN) [reported as the sum of NH_3, NO_3 and NO_2 concentrations], Carbonaceous Biochemical Oxygen Demand ($CBOD_5$), and Total Suspended Solids (TSS) as septic effluent moved through a state of Texas regulated minimum approved soil thickness (two feet). For purposes of this study any effluent that passes through the minimum two feet of soil represented in the columns is presumed to enter the groundwater. The contaminants were studied under normal loading conditions (without recharge) as well as immediately following recharge events. The recharge conditions were of particular interest because infiltration of precipitation could result in a significant difference in the concentration or mass of contaminants being introduced into groundwater. Several hypotheses were tested during this study.

Hypotheses

A. The concentrations of CBOD, TSS, and TIN of the septic effluent will be significantly less after flowing through the two feet of soil.

B. Finer grained soils will show a significantly greater decrease in the concentration of CBOD, TSS and TIN than coarser grained soils.

C. Recharge will significantly increase the mass of CBOD, TSS and TIN potentially entering groundwater per unit time.

Location

The study was conducted at the Baylor Wastewater Research Program (BWRP) facility, located at the Waco Metropolitan Area Regional Sewerage System, (WMARSS) Treatment Plant. The WMARSS facility is located about five-miles south of Waco in Central Texas (fig. 1). The BWRP facility was chosen for this study because of the regulated supply of wastewater and infrastructure already in place (septic tank, pumps and refrigerators).

Figure 1. Location of BWRP site along the Brazor River, five-miles southeast of WacoTexas

CHAPTER TWO

Methods

Experimental Design

To test the hypotheses a column study was designed to evaluate the effect of effluent dispersal and recharge events on groundwater below the 3 soil classifications (types) permitted by the TCEQ for use in septic leach fields. Those "types" include type Ib (sandy) soils, Type II (sand/silt) soils and Type III (silt/clay) soils. Precluded from use by the TCEQ, are the gravely soil (type Ia) because it is too highly permeable and clay soil (type IV) because of its low hydraulic conductivity (fig. 2).

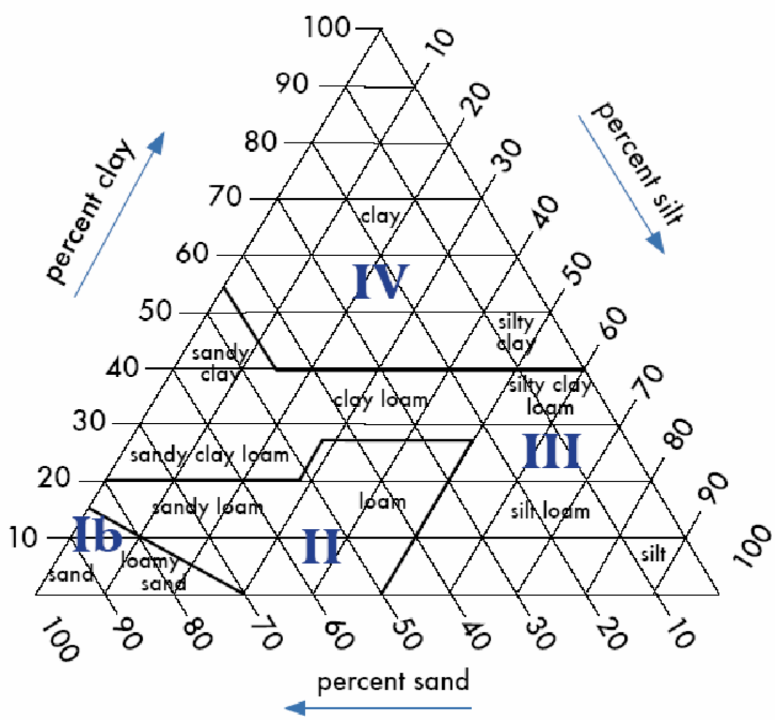


Figure 2. Texture triangle depicting the soil classes of interest in this study

In this study each soil type was tested in triplicate with soil columns A, B and C representing Type Ib Soils; D, E and F representing Type II soils; and G, H and I representing Type III soils. This use of triplicate columns allowed for variation among the soil columns for each soil type. During the study Column E failed and had to be abandoned.

Soils

The soils tested are representative of common soils permitted for septic tanks with leach fields across Texas, though all were collected within Hill County. Probable candidates, based on areal extent and USDA pedotype description were sampled to learn whether or not the soils were appropriate for use in an OSSF-leach field according the TCEQ. The soils were evaluated initially based on grain size and related USDA textural classification. Additional analysis of the soils used included quantifying cation exchange capacity, percent organic/inorganic carbon and clay type by a Siemens D5000 X-ray diffractometer (XRD). When collecting soils, the A-horizon was removed before collection in an attempt to isolate soil horizons from the depth that would be present in a leach field trench (Dawes and Goonetilleke, 2006). The soils that were chosen were the Silstid Loamy Fine Sand, Crockett Fine Sandy Loam and the Normangee Clay Loam.

The Silstid Loamy Fine Sand was used as a Type Ib soil and covers approximately 13,600 acres in Hill County. In addition to Hill County, the Silstid can be found throughout Central and Northern Texas and is described by the USDA as being "moderately expansive" in extent (NRCS Hill County Soil Survey, 1975). When collected, this soil had a field bulk density of 1.39 g/cm^3. Hydrometer analysis indicated that this soil is compromised of 87% sand, 7% clay and 6% silt sized particles. This soil was found to have a cation exchange capacity of 4.8 meq/100g, a 0.45 weight percent organic carbon and a C:N ratio of 11.25 (table 1). The XRD analysis showed that the clay constituent of this soil is predominately illite/kaolinite with a minor amount of smectite.

The Crockett Fine Sandy Loam covers approximately 16,800 acres in Hill County but can be found throughout the Blackland Prairies of Texas and minor areas in Oklahoma (NRCS Hill County Soil Survey, 1975). The series is "extensive" according to the USDA and meets the textural requirements to serve as a Type II soil. When collected, this soil had a field bulk density of 1.64 g/cm^3. Hydrometer analysis indicated that this soil is compromised of 64% sand, 14% clay and 22% silt sized particles. This soil was found to have a cation exchange capacity of 21.2 meq/100g, a 0.65 weight percent organic carbon and a C:N ratio of 13.00 (table 1). The XRD analysis showed that the clay constituent of this soil is smectite/kaolinite.

The Normangee Clay Loam covers approximately 32,800 acres in Hill County and is a suitable Type III soil. Similar to the Crockett series, the Normangee soil series can also be found in the Blackland Prairie and in parts of Oklahoma; but in addition, it can also be found in the Texas Claypan area. The Normangee soil is described as having "moderate extent" (NRCS Hill County Soil Survey, 1975). When collected, this soil had a field bulk density of 1.46 g/cm^3. Hydrometer analysis indicated that this soil is compromised of 62% sand, 21% clay and 16% silt sized particles. This soil was found to have a cation exchange capacity of 28.6 meq/100g, a 0.62 weight percent organic carbon and a C:N ratio of 15.50 (table 1). The XRD analysis showed that the clay constituent of this soil is dominantly smectite.

Table 1. Soil Properties

Soil Type	Sand %	Clay %	Silt %	g/cm^3 field moist	C.E.C (meg/100g)	Wt. % O.C.	C:N
Ib	87	7	6	1.39	4.8	0.45	11.3
II	64	14	22	1.64	21.2	0.65	13.0
III	62	21	16	1.46	28.6	0.62	15.5

Apparatus

The columns in this study were designed to mimic the hydraulics of a leach field. They were constructed of six-inch inside diameter PVC pipe and were filled with two feet of a representative soil overlain by eight inches of gravel. The effluent was dosed at 6 inches above the lower soil interface in the gravel layer. Above the gravel there are nine inches of soil in which grass was grown. The grass species was Common Bermuda and was planted as sod. The columns have access holes drilled in the upper nine inches of soil through which a soil moisture probe was inserted periodically to measure moisture content. These holes were covered with a stretched latex membrane so that moisture could not escape from the columns when soil moisture was not being measured (fig. 3).

The soil was packed to the density observed in the field where the soil was collected. Bulk density samples were collected using a Shelby tube in the field. This "field moisture" sample density was used to calculate how much soil mass would be needed to fill the volume within the soil columns to the correct density. This mass of soil was calculated and divided into six equal parts. The soil was introduced into the column and packed in a series of four-inch "lifts" or layers. The six, four-inch lifts yield a packed soil column with a bulk density equal to the bulk density observed in the field. While determining bulk density of each soil, the remainder of the collected sample was stored in sealed 5 gallon plastic pails to prevent drying. The columns were contained within a plywood enclosure to both protect them from extensive solar radiation and to maintain a more consistent temperature. During the winter a heater was placed in the column box with a thermostat set to activate at 10 °C.

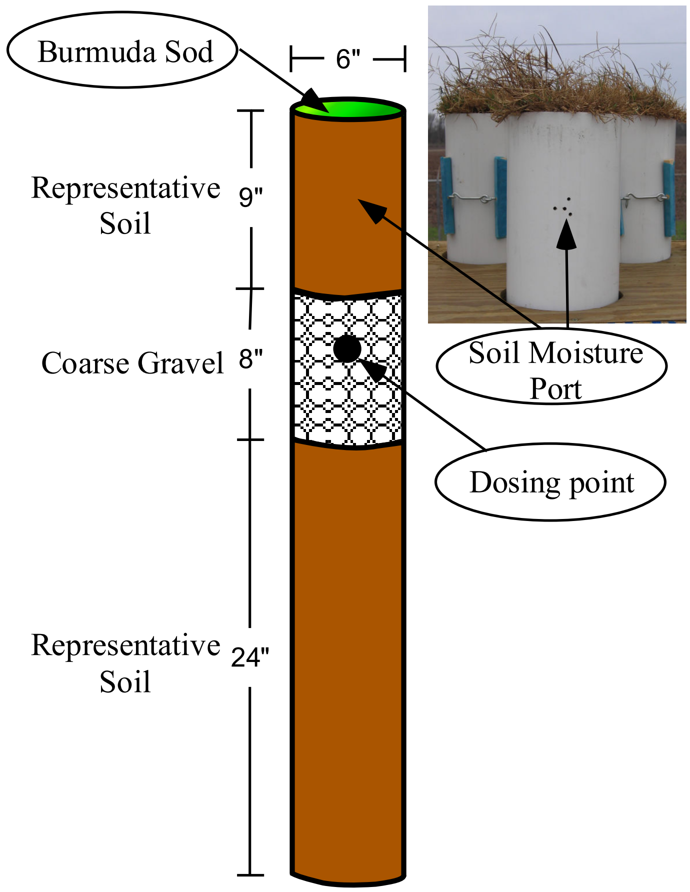


Figure 3. Soil Column Scale Illustration

Procedure

After the columns were constructed and the sod planted, a KBr tracer was used to identify any potential bypass flow and to quantify the residence time of each of the columns at the proposed dosing rates. Tracer testing indicated relatively homogenous residence times among replicates of soil types and no obvious bypass flow with average residence times equaling 22, 35 and 45 hours for Types Ib, II and III respectively (fig 4).

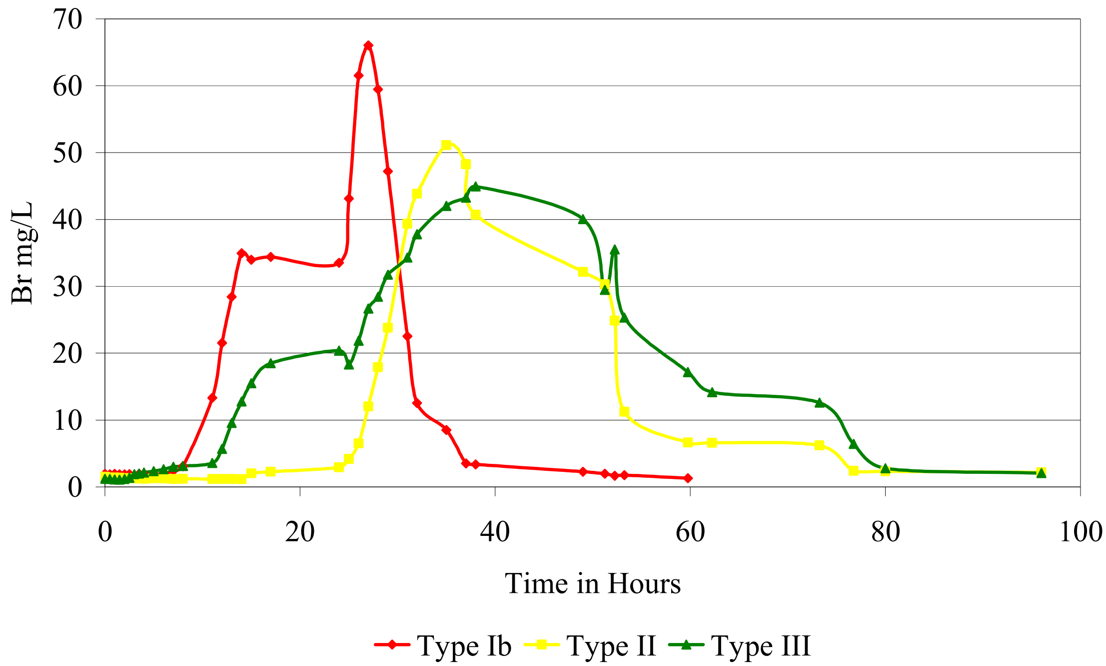


Figure 4. KBr tracer retention time by soil type

The columns were dosed with septic effluent from a two-chambered 1500-gallon septic tank. This tank was dosed with 500 gallons of municipal wastewater per day. The septic effluent was dosed to the columns three times daily in amounts consistent with the ANSI (American National Standards Institute) Standard 40 dosing schedule for design loading (NSF International, 2005). This dosing schedule is designed to simulate average household uses of water. This schedule assumes that 35% of the daily water usage will occur in the morning with resident bathing and cleaning up after breakfast, 25% of the daily water usage during lunch time when fewest people are at home and 40% of the usage occurring in the evening hours with residents cooking, cleaning and possibly doing laundry. This is the standard that NSF uses to certify various On-Site systems (NSF International, 2005). The amount of septic effluent dosed to the soil columns was based on the soil type and the surface area of the columns. As dictated in various regulations, the coarser Type Ib soils received proportionally more effluent than Type II soils. The Type III soils were dosed with the least effluent. For the first 18 weeks of dosing and up to and including the first rain event the columns were dosed at the maximum application rate for each soil type outlined by the TCEQ. TCEQ, determines dosing volume based on the absorptive area of the trench as well as the soil texture which is used to determine the long term application rate (LTAR). Using TCEQ's guidelines the LTAR and absorptive area that would be associated with this experimental design (a 6" circular cutout of a leach field) is shown in tables 2 and 3.

These values assume trench sidewall permeability and since the pvc pipe analog used does not have sidewall permeability, the columns were being over-dosed with sewage. This developed the soils more rapidly but during this time, a Type II soil column, Column E failed hydraulically; resulting in dosed effluent saturating the column entirely and ponding on the sod surface. This rate was excessive without sidewall permeability. A rate prescribed by the state of North Dakota (Scherer, 2006), that does not consider trench sidewall permeability, was used after week 18 (table 4). This loading rate was multiplied by the bottom area of the columns (table 5) to calculate today daily volumes per column as shown in table 6.

The greater dosing volumes that were initially used provided enough column effluent to test all desired parameters on a 24-hour composite basis. With the amended dosing rates, the sampling frequency was changed to 48-hour composites, analyzed immediately, to provide a sample volume adequate for analysis. Ammonia analysis was performed using a Hach Sension4 meter and a gas sensing electrode. Nitrate and nitrite samples were analyzed using a Hach DR2400 Spectrophotometer and provided vacuum ampules. CBOD and TSS was analyzed by the city of Waco Wastewater Lab.

Table 2. TCEQ Area and LTAR Calculations for a 6” diameter soil column

Bottom Area πr^2	Sidewall Area $2 \pi r h$	Total Area Bottom + sidewall	Total Area(ft^2) (in^2) / 144
28.26	226.08	254.34	1.77

The absorptive area consists of the bottom area of the excavation plus one foot of sidewall area around the full perimeter of the excavation.

Soil Type	Max. Long Term Application (R_a) Gal/ft^2/day	Total Area(ft^2)
Ib	0.38	1.77
II	0.25	1.77
III	0.20	1.77

Table 3. Effluent dosing volumes by soil type

Soil Type	Total Dosage Per day 100%	Morning 6 - 9 AM 35%	Noon 11 AM - 2 PM 25%	Evening 5 - 8 PM 40%
I b	2,536 ml	888 ml	634 ml	1014 ml
II	1,666 ml	583 ml	416 ml	666 ml
III	1,325 ml	464 ml	331 ml	530 ml

Table 4. Revised loading rates

Soil Texture	Trench bottom loading rate, gal/ft^2/day	
Sand and loamy sand	1.20	Type Ib
Sandy loam	0.80	Type II
Fine sand, very fine sand, loam	0.60	
Silt and silt loam	0.50	
Clay loam, sandy clay, silty clay loam	0.45	Type III
Clay	0.23	

Table 5. Inputs for calculating new dosing rates

Soil Type	Soil Texture	Loading Rate(gal/ft^2/day)	Total Bottom Area(ft^2)
Ib	Loamy Sand	1.2	0.20
II	Sandy Loam	0.8	0.20
III	Clay Loam / Sandy Clay	0.45	0.20

Table 6. Revised daily volumes of dosed effluent

Soil Type	Total Dosage per day 100%	Morning 6 - 9 AM 35%	Noon 11 AM - 2 PM 25%	Evening 5 - 8 PM 40%
I b	908 ml	318 ml	227 ml	363 ml
II	606 ml	212 ml	152 ml	242 ml
III	340 ml	119 ml	85 ml	136 ml

An ANOVA was performed comparing the treatment efficiencies on a percent removal basis of the columns under the higher dosing regime with those collected under the lower dosing regime. The differences in CBOD and TIN were insignificant with an α of 0.05. The percent removal of TSS was actually found to have significantly decreased by 17.2%, representing an increase in TSS concentration of the fluid leaving the columns, with the decrease in dosing volume. Veneman and Stewart, (2002) did a similar study involving gray-water, during which the dosing volumes were double mid-way through the study. They found that this increase in volume did not result in a significant change in biochemical oxygen demand (BOD_5) TSS and TKN concentrations at an α of 0.05.

During the study, the columns were shielded from precipitation by a 4-mil clear plastic film suspended by a frame several feet above the top of the columns. This allowed the columns to be influenced by the local climate (humidity, winds, temperature and sunlight) but prevented recharge except when artificially introduced. The columns as built and during the study are shown below in figure 5.

Figure 5. Soil column apparatus showing top of the septic tank (green riser) from which effluent was pumped, the heated wooden enclosure helped prevent freezing and maintain fairly consistent temperature at "depth" and the rain shield above the columns.

The columns were subjected to recharge events using a rainulator. Rainulators have been in use since as early as 1967 and are used to simulate rainfall events by reproducing duration and intensity of a rainstorm over a known parcel size (Centeri and others, 2001). The rainulator used in this study consisted of eight 0.8 gal/min radial spray nozzles mounted on a frame suspended approximately six feet above the surface of the soil columns in such a way that there was nearly uniform coverage at the column level. The volume of rainfall dosed to the columns was regulated by cycling the pump on and off incrementally during the event simulation. To allow the precipitation on the columns to mimic actual leach field conditions, a hole was drilled in the side of the columns at the surface of the sod to runoff which was collected. The volume of runoff associated with each storm was noted for each soil column (APPENDIX B). To protect from prevailing winds the rainulator was shielded using sturdy plastic sheeting held taught through the use of various cross braces and tape. (fig. 6). The study consisted of 25 weeks of data collection commencing on October 9, 2006 and concluding on March 30, 2007. During this study three precipitation events were artificially reproduced. The first event evaluated effluent quality following a five-year frequency, two-hour storm. The second event evaluated effluent quality following a twenty five-year, two-hour storm. The third event evaluated effluent quality following a fifty-year, two-hour storm. This events and associated dosing regimes are depicted in Figure 7.

Figure 6. Soil columns during a rain event simulation showing the rainulator, rain gauges and protective plastic windshield to help maintain even rain distribution

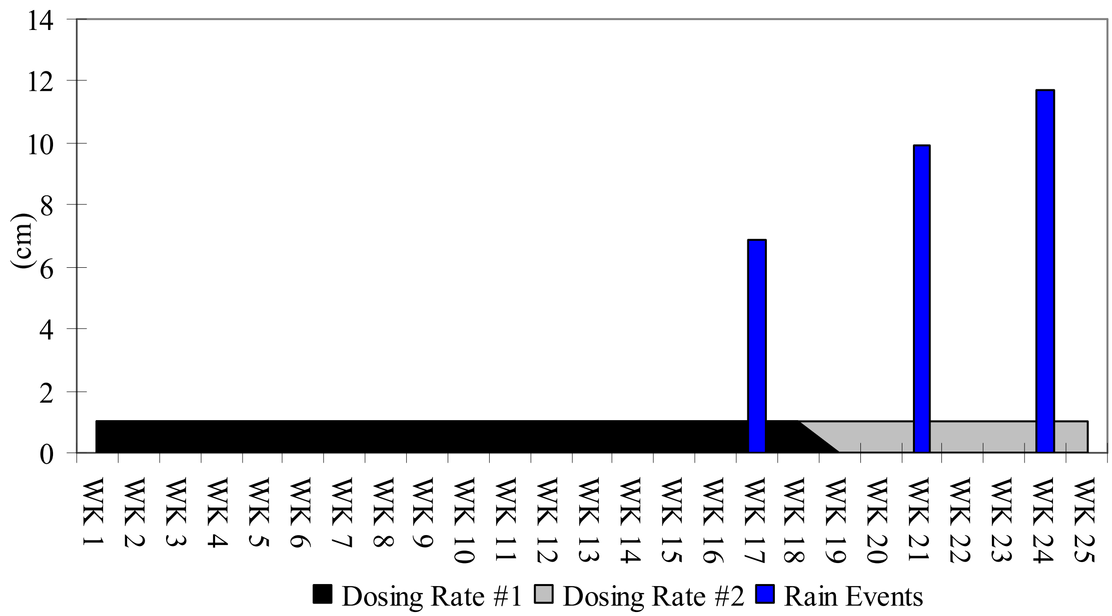


Figure 7. Study timeline

Volumetric soil moisture was measured frequently and a rain event was simulated only after the soil moisture had stabilized at a consistent level. Moisture levels from the weeks prior to each storm are shown in table 7. These storms were chosen because a 5-year storm would likely occur multiple times during the life of a leach field as might the 25-year storm. The 50-year storm frequency, has a lower probability of occurring, but is always a possibility and was thought to be a worst case scenario that one may reasonably expect to occur in the lifespan of a leach field. The two-hour duration was chosen because it duplicates typical storm patterns over the area for smaller watersheds. It was also more reasonable to regulate the water over a two-hour period than for 24 hours or more.

Table 7. Average soil moistures (%volumetric moisture) prior to each rain event, by soil type

Storm Frequency	Soil Type Ib	II	III
5 year	10.2	9.7	0.3
25 year	6.6	3.9	0.4
50 year	6.8	3.1	1.2

Temperature

Temperature was measured throughout the study because it can affect wastewater degradation or treatment processes in soil. The difference between monthly maximum and minimum average daily temperatures (^oC) were recorded in order to gain an understanding of the daily variation in temperatures (table 8). In addition to this the monthly mean daily temperatures were recorded (table 9). These values were recorded in ambient air, under 6-inches of soil at the BWRP site and from a data logger within the soil column box.

Table 8. Difference in maximum and minimum average temperatures (^oC) by month and over the duration of the study for temperature data loggers placed in ambient air, inside the column box and buried in soil on-site

Location	Oct	Nov	Dec	Jan	Feb	Mar	average
Air	15.7	16.3	13.9	10.4	15.0	13.4	14.1
Column Box	15.8	16.7	10.8	7.1	10.2	9.0	11.6
Soil	0.8	1.0	0.8	1.1	1.3	1.3	1.0

Table 9. Mean temperature (^oC) values by month from data loggers placed in ambient air, inside the column box and in soil on-site as well as a historical mean (NCDC, 2000)

Location	Oct	Nov	Dec	Jan	Feb	Mar	Average
Mean Air	23.6	16.7	12.4	8.1	12.8	18.8	15.4
Mean Column Box	21.0	15.4	11.8	7.0	11.6	17.8	14.1
Mean Soil	21.7	16.8	12.8	9.8	11.5	16.1	14.8
Historical Mean (air)	19.7	13.4	8.7	7.3	9.9	14.4	12.2

CHAPTER THREE

Results

Temperature

The monthly mean temperature (^oC) variation depicted in table 8 shows that the buried temperature data logger fluctuated only 1 (^oC) on average, while the column box data logger and the ambient air data logger had monthly temperature variances of 11.6 and 14.1 (^oC) respectively. The monthly mean daily temperatures (table 9) of the soil, column box, and ambient air all differ by less than 2 (^oC)

Background Steady-State Loading Data

Data from the first six weeks of this study are not representative of the mature or developed column performance. During this time, the columns were developing as treatment units. Evidence for this development included abnormally elevated Nitrite concentrations (fig. 8) and extremely low Ammonia levels (fig. 9) during the first six weeks. CBOD concentrations during this period were also anomalous, depicting near perfect removal rates with no apparent relation to septic concentrations (fig. 10).

After the first six weeks the columns were approaching chemical stability or maturity which appears to have been attained by week twelve. Therefore, statistical analysis was performed only on data collected after week six. During the course of this study Column E, a replicate of a Type II soil, hydraulically failed. With the loss of Column E triplicate analysis was only possible with the Type Ib soils and the Type III soils. Type II soils were only represented with replicates, Columns D and F. Influent and effluent concentrations and percent removal (eqn. 1) statistics (mean value and standard deviation) for CBOD, TSS and TIN are shown in tables 10 and 11.

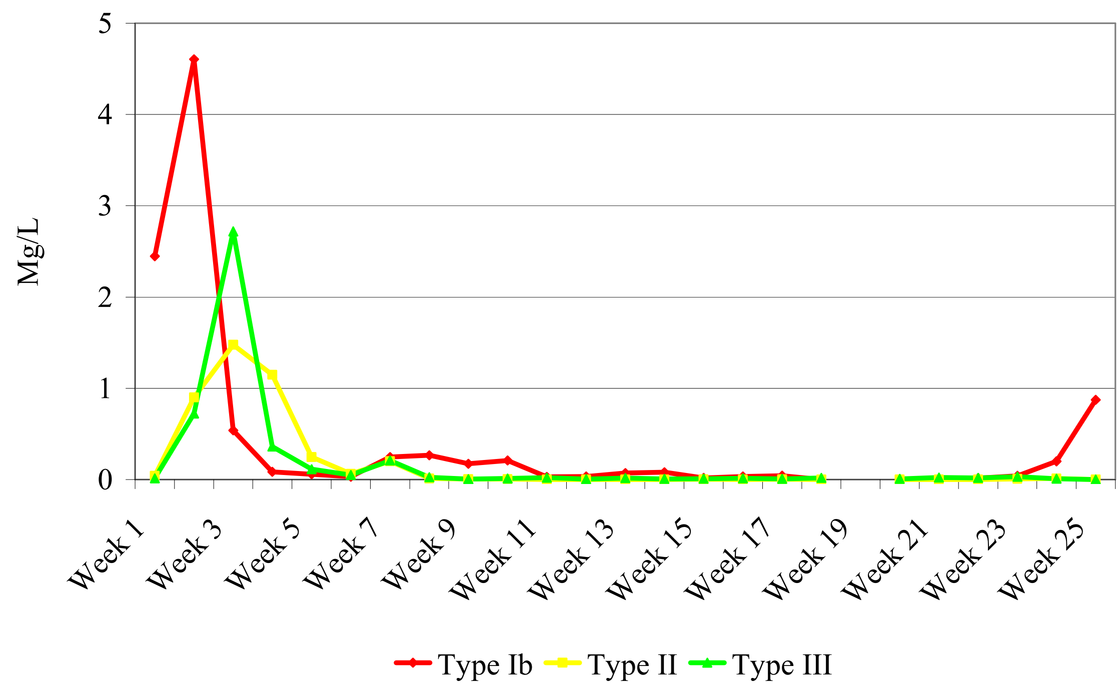


Figure 8. Nitrite concentration over the duration of the study by soil type

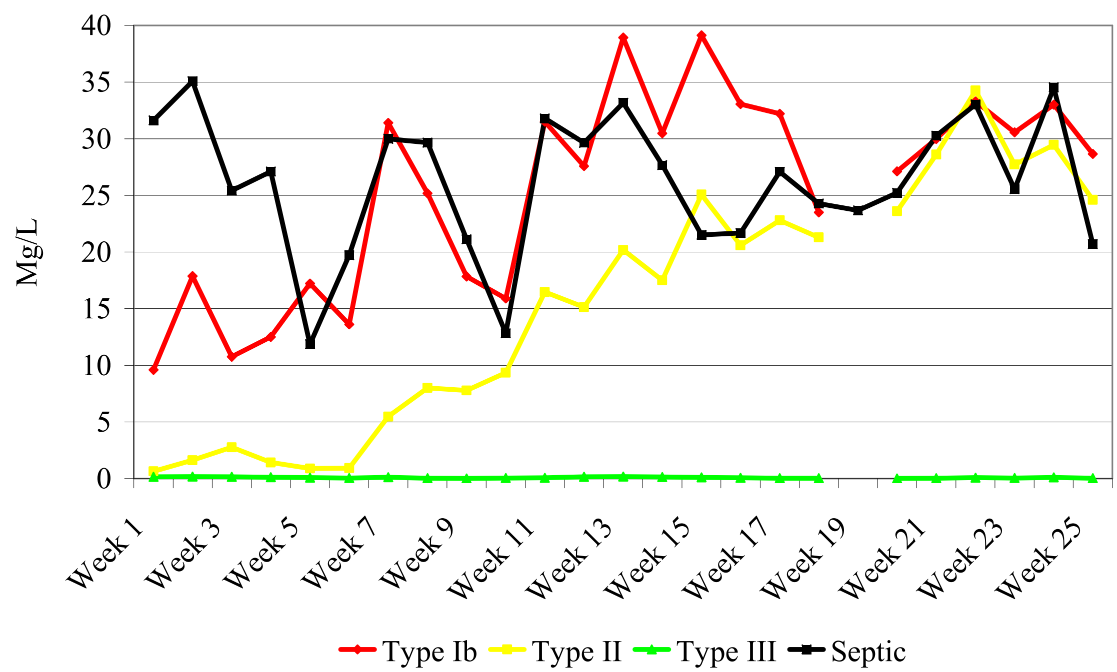


Figure 9. Ammonia concentration over the duration of the study by soil type

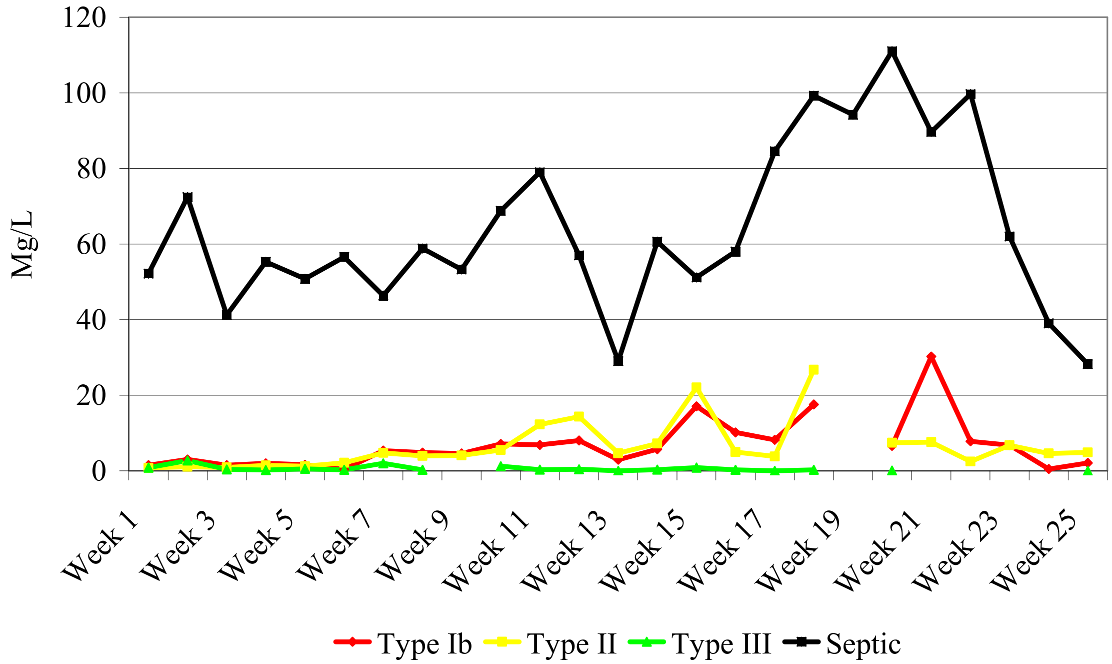


Figure 10. CBOD concentrations over the duration of the study by soil type

Equation 1. Percent removal

$$\frac{(\text{Septic Concentration} - \text{Column Concentration})}{\text{Septic Concentration}} \times 100 = \text{Percent Removal}$$

Table 10. Total mean concentrations and percent removal (rounded to the nearest 1%) of analytes by soil column

		Septic	A	B	C	D	F	G	H	I	min	mean	max
CBOD	mg/L	66.8	7.0	9.6	7.8	7.3	9.2	0.7	0.4	0.4	0.4	5.3	9.6
	Std. Dev.	24.3	4.2	11.8	7.6	5.6	8.6	0.9	0.5	0.6			
TSS	mg/L	23.6	10.4	8.8	8.4	5.8	13.9	3.4	2.6	3.0	2.6	7.0	13.9
	Std. Dev.	8.0	8.0	9.9	8.5	5.0	3.2	4.8	2.1	2.1			
TIN	mg/L	34.8	31.3	30.6	30.2	21.1	22.1	11.2	10.6	12.4	10.6	21.2	31.3
	Std. Dev.	7.3	6.8	7.3	6.8	7.3	10.0	4.4	3.3	3.2			
		Septic	A	B	C	D	F	G	H	I	min	mean	max
CBOD	% removal	n/a	88	87	88	87	86	99	99	99	86	91	99
	Std. Dev.	n/a	6.8	12.5	14.2	10.4	11.6	1.5	1.1	1.2			
TSS	% removal	n/a	51	66	64	72	33	86	88	87	33	64	88
	Std. Dev.	n/a	37.7	33.3	31.9	27.9	18.5	16.7	11.0	9.3			
TIN	% removal	n/a	8	10	10	39	37	67	68	63	8	34	68
	Std. Dev.	n/a	21.4	24.2	26.7	19.5	28.0	14.3	11.9	12.1			

Table 11. Mean concentrations and percent removal within each soil type

		Septic	Type Ib	Type II *	Type III
CBOD	mg/L	66.8	8.2	8.2	0.5
	Std. Dev.	24.3	3.8		0.2
TSS	mg/L	23.6	9.1	9.9	3.0
	Std. Dev.	8.0	1.0		1.6
TIN	mg/L	34.8	30.7	21.6	11.4
	Std. Dev.	7.3	0.3		0.6

		Septic	Type Ib	Type II*	Type III
CBOD	% removal	n/a	87	87	99
	Std. Dev.	n/a	3.9		0.2
TSS	% removal	n/a	61	52	87
	Std. Dev.	n/a	3.0		3.8
TIN	% removal	n/a	10	38	66
	Std. Dev.	n/a	2.7		1.4

* Type II soils had only two replicates, so the mean expressed is not a true mean and standard deviation values were not calculated.

Carbonaceous Biochemical Oxygen Demand

CBOD concentration in the septic effluent had a mean of 67 mg/L but was highly variable with a standard deviation of 24 mg/L and minimum and maximum weekly average values of 28 and 111 mg/L respectively. After flowing through the Type Ib columns CBOD concentration was reduced an average of 87%. The Type II soils were equally effective. However, the Type III soils were the most effective at decreasing CBOD concentrations. The Type III soils decreased CBOD by an average of greater than 99% (table 11).

Total Suspended Solids

TSS concentration in the septic effluent had a mean of 24 mg/L with a standard deviation of 8 mg/L and minimum and maximum weekly average values of 13 and 38 mg/L respectively. After flowing through the Type Ib columns this was reduced an average of 61%. The Type II soils were the least effective, decreasing TSS concentrations by only 53%. Again, the Type III soils were the most effective at decreasing TSS. The Type III soils decreased TSS by an average of 87% (table 11).

Total Inorganic Nitrogen

TIN concentration in the septic effluent had a mean of 35 mg/L with a standard deviation of 7 mg/L and minimum and maximum weekly average values of 17 and 52 mg/L respectively. After flowing through the Type Ib columns this was reduced an average of 10%. The Type II soils were slightly more effective, decreasing TIN concentrations by 38%. Again, the Type III soils were the most effective. The Type III soils decreased TIN by an average of 66% (table 11).

Statistical Significance

An ANOVA analysis found a strong statistically significant difference among the treatment efficiencies among all thee soil types concerning TIN. When analyzing the differences in CBOD and TSS treatment, in both instances, Type I and Type II soils were found to be different from Type III soils, but not from each other.

Rain Events

Simulated recharge events were conducted in weeks 17 (January 30, 2007), 21 (February 28, 2007) and 24 (March 21, 2007) of this study mimicking the 5-year, 25-year and 50-year, two-hour storm at those respective dates. The volume of rain associated with each storm event was 6.85 cm, 9.92 cm and 11.68 cm respectively (fig 7.) (Asquith and Roussell, 2004). Data collected the week prior to each rain event, data collected during 96 hours after each rain event and data from the next 96 hours were analyzed to quantify the effects of recharge on the soil columns. The 96 hours of data collected immediately after the rain event were classified as “event” data. The data from the previous week and the 96 hours following this period were classified as “background” data. The means from the background data and the event data were compared and the difference divided by the mean background data and recorded as percent removal or as percent removal

Carbonaceous Biochemical Oxygen Demand (mass flux)

The 5-year, two-hour storm resulted in an increase in percent removal or decrease in mass of CBOD for all soil types. The two other recharge events, the 25-year and 50-year, two-hour storms resulted in a decrease in percent removal, or increase in mass of CBOD for all soil types with the exception of the 25-year, two-hour storm in the type II soils which exhibited a slight increase in efficiency, or decrease in mass. For the same 25-year event, the Type III soils showed no change in percent removal when comparing background to event data (fig. 11).

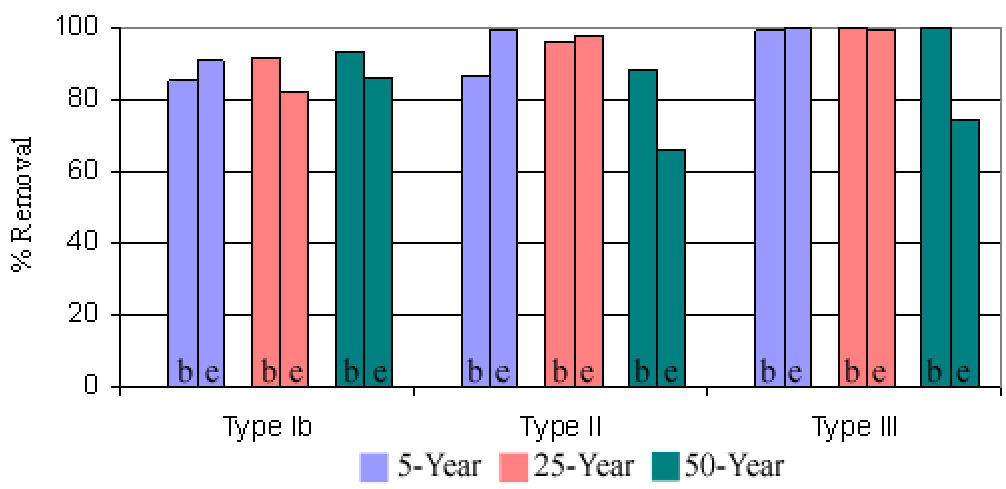


Figure 11. Comparison of background (b) and event (e) percent removal of CBOD for the different soil types on a mass flux basis.

Total Suspended Soils (mass flux)

The column treatment efficiencies in terms of mass removal of TSS leaving the columns decreased in both Type Ib and Type III soils following all three rain events as compared to background data. This decrease in percent removal again represents an increase in the mass of TSS leaving the columns. Type II soils conversely showed a slight increased percent removal following the 5-year and 50-year, two-hour storms and a decrease following only the 25-year, two-hour storm (fig. 12).

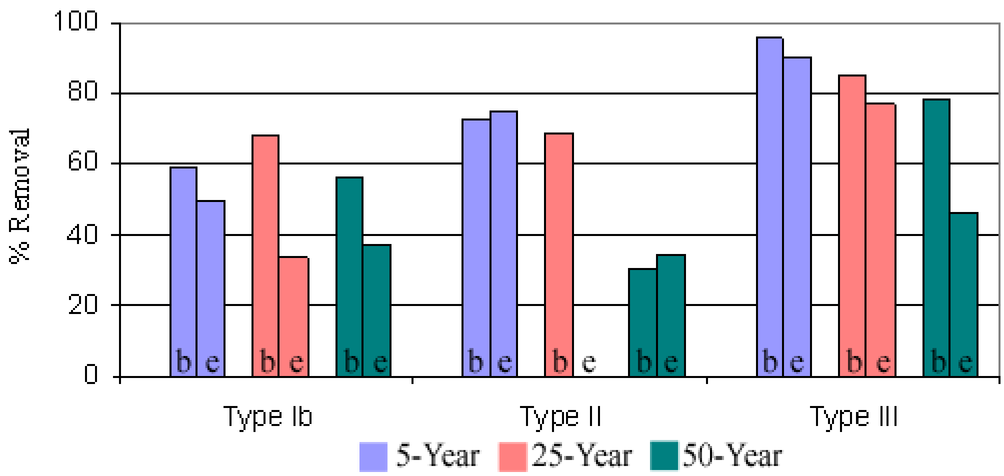


Figure 12. Comparison of background (b) and event (e) percent removal of TSS for the different soil types on a mass flux basis

Total Inorganic Nitrogen (mass flux)

The 5-year, two-hour storm resulted in a decrease in mass of TIN for each respective soil type and appears as an increase in percent removal. The two other recharge events, the 25-year and 50-year two-hour storms, resulted in an increase in mass of TIN for each soil type. The only exception occurred in the type II soils during the 50-year, two-hour storm which exhibited a slight decrease in mass flux (fig. 13).

Carbonaceous Biochemical Oxygen Demand (concentration)

Using the same samples that were used in mass flux analysis, mean concentration values were compared without consideration for volume differences between normal dosing rate and recharge events. The 5-year, two-hour storm resulted in an apparent increase in the percent removal of CBOD in Type Ib and Type II soils, but no change in efficiency in Type III soils. The 25-year, two-hour storm resulted in a decrease in percent removal of CBOD in Type Ib soils, an increase in Type II soils and no change in Type III soils. However, the 50 year, two-hour storm resulted in a decrease in percent removal of CBOD among all soil types (fig. 14).

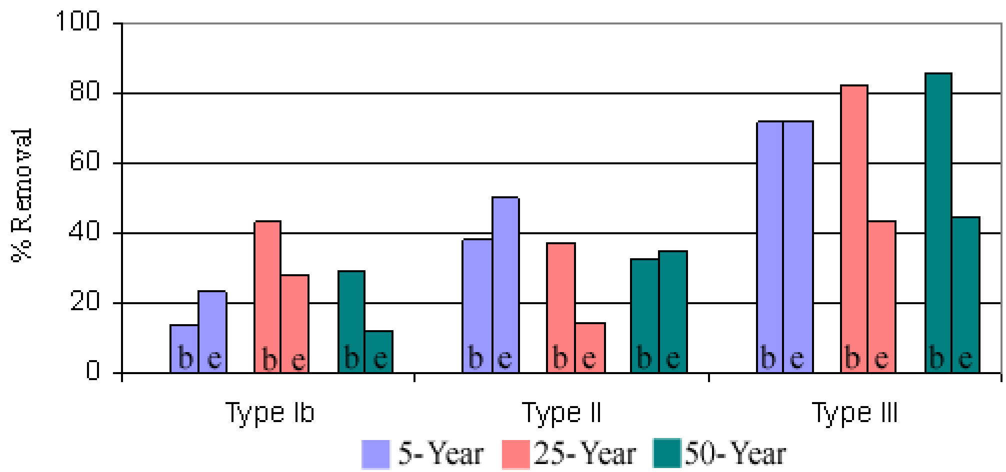


Figure 13. Comparison of background (b) and event (e) percent removal of TIN for the different soil types on a mass flux basis

Total Suspended Solids (concentration)

The 5-year, two-hour storm resulted in an increase in the percent removal of TSS in Type Ib and II soils, but a decrease in efficiency in Type III soils. The 25-year, two-hour storm resulted in a decrease in percent removal of TSS in Type Ib and Type II soils, but an increase in Type III soils. However, the 50-year, two-hour storm resulted in an increase in percent removal of TSS among all soil types (fig. 15).

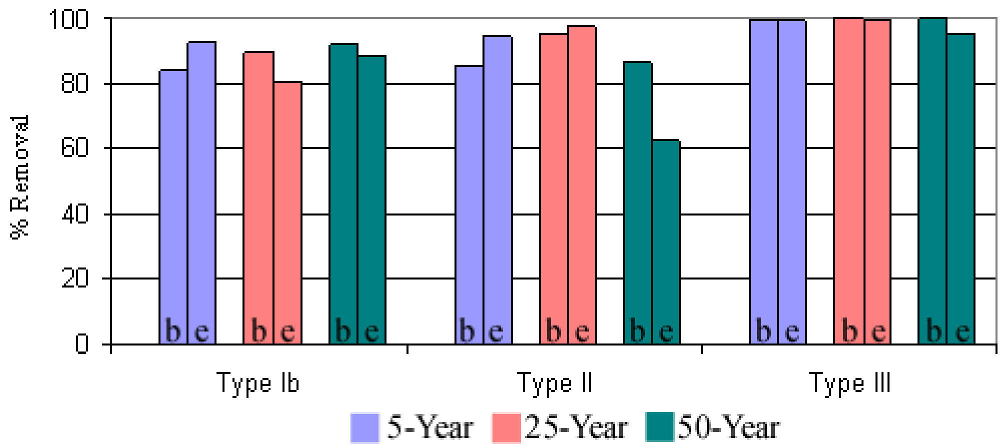


Figure 14. Comparison of background (b) and event (e) percent removal of CBOD for the different soil types on a concentration basis.

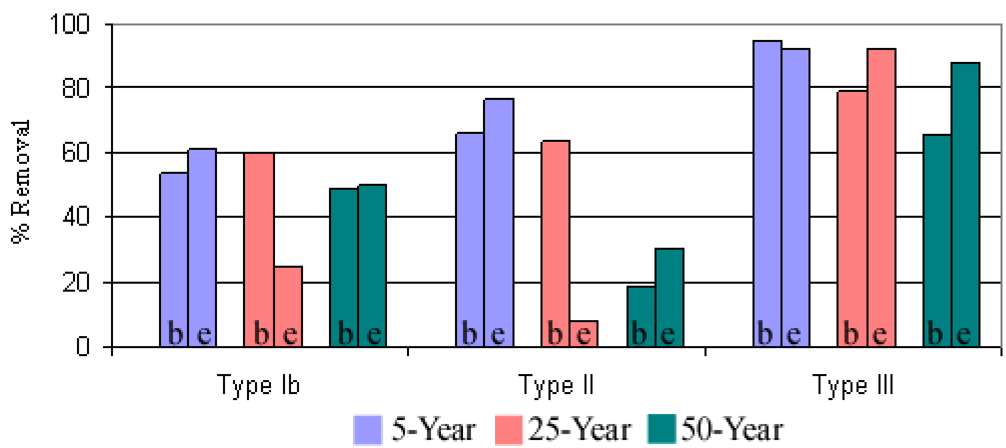


Figure 15. Comparison of background (b) and event (e) percent removal of TSS for the different soil types on a concentration basis

Total Inorganic Nitrogen (concentration)

The 5 and 50 year, two-hour storms showed an increase in percent removal relative to TIN reflecting a decrease in concentration of the TIN exiting all soil types.

Following the 25 year, two-hour storm, a decrease in percent removal, or increase in concentration was observed in all soil types (fig. 16).

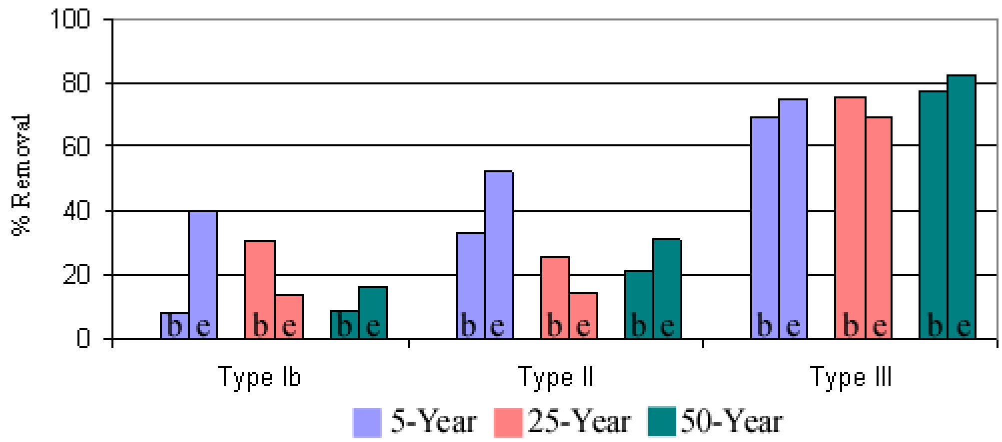


Figure 16. Comparison of background (b) and event (e) percent removal of TIN for the different soil types on a concentration basis

CHAPTER FOUR

Discussion

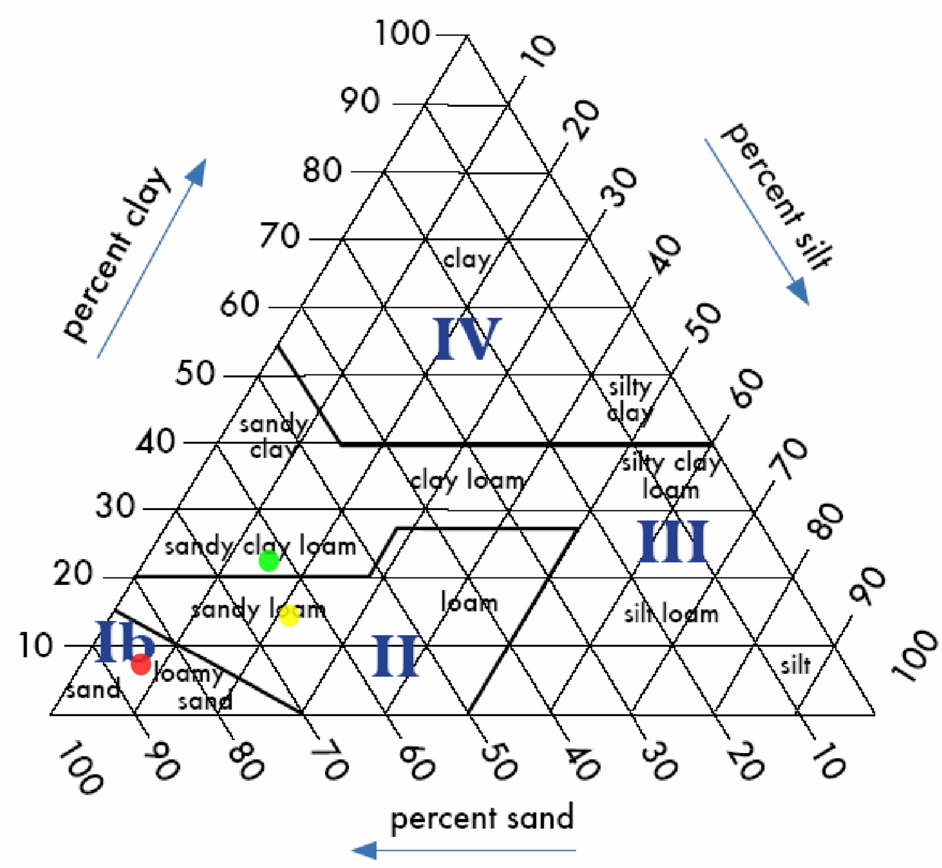
Temperature

The column box appears to not have been 100% effective at controlling for temperature variation. This is expressed in table 8 where variance in temperature was greater in the soil column box, than in actual buried soil, but it was less than in ambient air. It should be noted that the temperature sensor was placed on the floor of the column box and that the actual temperature inside the soil columns probably had less variance and a higher mean. The sensor was placed in the column box, rather than in the column because it was though that burying the sensor in the columns would provide an avenue for by-pass flow and undermine the integrity of the columns. The column box temperature should be viewed as a worst case scenario in terms of temperature variability however not in temperature mean. When considering strictly mean monthly temperatures, there was minimal difference in temperature between the buried data logger, the data logger in the column box and the data logger in ambient air. Also, all of the recorded temperatures were within 3 ^{o}C of the historical mean temperature for this study period (table 9). Considering this information, temperature was thought to not be a major factor in the soil column performance. It is true that significant temperature variation will impact nitrification and subsequent de-nitrification (Breuer and others, 2002 and Stark, 2006). However, there was no apparent decrease in percent removal of any of the analytes within the columns as the temperature decreased.

Background Steady-State Loading Data

As hypothesized there was significant treatment of the septic effluent by the two feet of soil in the columns. Variability of the effluent treated by the different soil types has many underlying causes. The most obvious of which is grain size or soil texture. It is from soil texture that dosing volume is determined. Also, the average linear pore velocity is inferred to be slower in the finer soils as evidenced by the retention time determined through the KBr tracer test (fig. 3). Subsequently the end result is that the most sandy, coarse soil (Type Ib) is being dosed with the greatest volume of septic effluent and retains it for the shortest period of time. The finest, most clay rich, Type III soils are being dosed with the least volume of septic effluent and retain it the longest. The intermediate Type II soils contain the median amount of clay, are dosed at the median daily volume and have the median retention time of all the soils considered. It should be noted that all conclusions drawn are based on these particular soils studied. They were intended to represent a sample from each particular approved soil type, but in no way encompass the entire variability associated with a particular soil type. This logic is bolstered by figure 17 showing the high degree of variability in soil classes, particularly in Type III soils.

The longer the retention time within each respective soil type, the greater the possibility for biochemical degradation to occur and decrease the amount of CBOD flowing through each respective soil column. The same is partially true for TSS concerning the organic constituent of the suspended solids, but not for the inorganic particulate matter which is either filtered out of suspension or flushed out of the column



Silstid Loamy Fine Sand (Sand: 86%, Clay: 7%, Silt: 6%)

Crockett Fine Sandy Loam (Sand: 64%, Clay: 14%, Silt: 22%)

Normangee Clay Loam (Sand: 62%, Clay: 21%, Silt: 16%)

Figure 17. Soil texture triangle showing the specific soil textures in relation to soil type

There was a definite maturation period in the soil columns. Early ammonia data indicates that all of the soil columns appear to be removing ammonia (NH_3) with a high level of removal. However, as the study progressed, the ammonia levels began to increase in the Type Ib and II soils. At the end of the study ammonia concentrations in the Type Ib and Type II soils nearly parallel the septic effluent concentrations but at a slightly lower value. This gradual decrease in NH_3 (fig. 9) removal might be explained by the available cation exchange capacity of these soils. Type III soils with the most clay may still be actively adsorbing ammonium cations (NH_4^+) to clay particles and organic matter in the columns. Since the Type III soils are receiving the least amount of effluent they could possibly still have available exchange sites and not yet show an increase in NH_3 concentration (fig. 9). An alternate explanation and indication for column maturity is that some of the NH_3 is being converted to NO_3 in Type III soils (fig. 18).

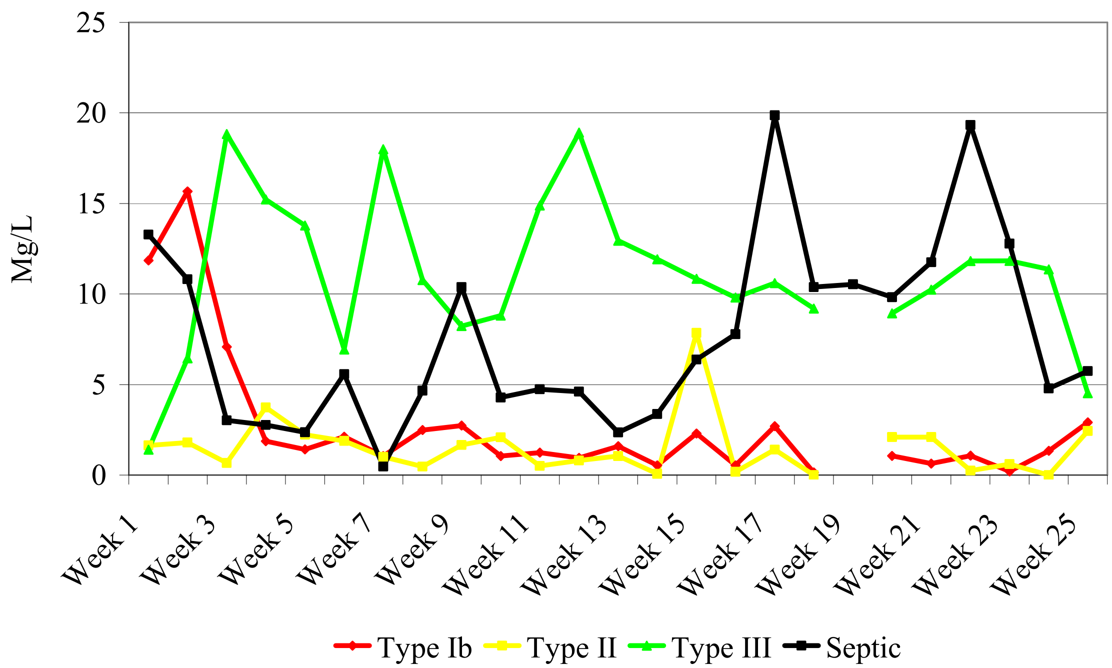


Figure 18. Nitrate concentrations over the duration of the study by soil type

Another instance of evidence supporting the notion that columns matured with respect to TIN is Nitrite (NO_2) concentration. Although NO_2 was never a major constituent in the calculation of TIN, NO_2 concentrations peaked by week three of the study and decreased below 1.0 mg/l for the remainder of the study (fig. 8).

Looking at the early trends in nitrogen data, some form of maturation was ongoing for the first several weeks of the study. After this maturation period, TIN treatment efficiencies mimicked the trends observed in CBOD and TSS background data.

It is thought that the Type Ib and Type III soils are representative of what could be expected from Ib and III soils in leach fields. This thought is not as strongly supported in the Type II soils. Reasons for this include that the Type II soils were only replicated by duplicates, not triplicates and there is that much more chance for outliers to go undetected. Furthermore, Type II soils showed a significant difference in percent removal of TSS between Columns D and F was statistically different ($\alpha = .05$) with a P-value of < 0.001. This relationship was not observed in any other soils, for any other parameter.

Rain Events

During the 5-year, two-hour storm, approximately 6.51 cm of rain fell on the soil columns. In the 25-year and 50-year, two-hour storms 9.44 cm and 11.66 cm of rain fell on the columns. Over the three precipitation events the Type Ib, II and III soils had average infiltration fraction of 74.5%, 50.4% and 100% respectively. The Type III soil's high infiltration fraction can most likely be attributable to desiccation cracking (predominantly around the perimeter of the soil column). This is a phenomenon not unique to column analogs, and has been noted with in-situ soils of similar texture (Arnold and others, 2005). For the soils columns that did yield runoff, accepted Soil Conservation Service methods explained by Wanielista and others (1997), were used to determine curve numbers. Both Type Ib and Type II soils had average curve numbers coincident with what would be expected for soils in the USDA hydrologic groups A and

D, respectively, with “fair” to “good” grass coverage. Also, although the background soil moisture levels were constant, the initial soil moisture before the 5-year storm was noticeably greater than it was prior to the 25-year and 50-year storms. This could possibly be attributed to the higher dosing volumes that were being used up to and including the 5-year storm.

Five-year, Two-hour Rain Event

The smallest of the rain events, the 5-year storm suggests that the primary process occurring in this smaller storm is dilution. Evidence for this is a decrease in mass and in concentration of TIN and CBOD leaving all the soil columns as compared to background data. The only exception to this decrease was the CBOD concentration in the Type III soils, which did not change. TSS on the other hand shows an increase in mass in Type Ib and III soils but a decrease in mass in the Type II soils. TSS concentrations decreased in Type Ib and II, but increased slightly in Type III soils. This suggests that, strictly relative to TSS, flushing occurred in Type Ib and III soils and that dilution occurred in Type II soils.

Twenty-five-year & Fifty-year, Two-hour Rain Events

The larger two rain events, the 25-year and 50-year storms, which are volumetrically similar (9.44 cm and 11.66 cm respectively) shared a “flushing effect” on the soil columns. During both of these events the mass of TIN increased dramatically in all instances except the 50-year storm in the Type II soils. Concentration of TIN also decreased dramatically in all instances other than the 25-year storm in the Type II soils. CBOD was increased in both concentration and mass in all soil types except for the Type

II soils. TSS increased in mass for both storms in type Ib an III soils. However, Type II soils TSS mass only increased during the 25-year storm. The concentration of TSS during the 25-year storm decreased in Type III soils and in all soils for the 50-year storm.

It should be noted that the 50-year storm occurred fairly quickly after the 25-year storm (three weeks). Although the soil columns had already returned to soil moisture levels similar to the pre 25-year storm conditions, the columns may not have recovered completely to a stable condition following the significant flushing from the 25-year storm.

CHAPTER FIVE

Summary and Conclusions

The dispersal of septic tank effluent into soils contributes significantly to the treatment of the wastewater but is strongly affected by texture.

- The percent removal of the traditionally regulated parameter, CBOD, ranged from nearly 87% in the Type II (sandy loam) soils to a mean of 99% in Type III (clay) soils.
- The percent removal of the traditionally regulated parameter, TSS, ranged from 52% in the Type II soils to a mean of 87% in the Type III soils.
- The percent removal of TIN was strongly affected by texture. The percent removal was much less in the Type Ib (sandy) soil, (10%), greater in the Type II soil, (38%) and greatest in the Type III soil (66%) The low percent removal in the Type Ib soil warrants more study with regard to nutrient treatment in the subsurface below leach fields.

Simulated recharge events affected the soil treatment of the wastewater.

- The smallest event, a 5-year, two-hour storm actually diluted the effluent causing a decrease in concentration and a decrease in total mass flux.
- The larger two events appeared to wash effluent through the column at such a rate that they increased the mass flux and decreased the percent removal in soil types Ib and III. The effects are not as clear in the Type II soils but this

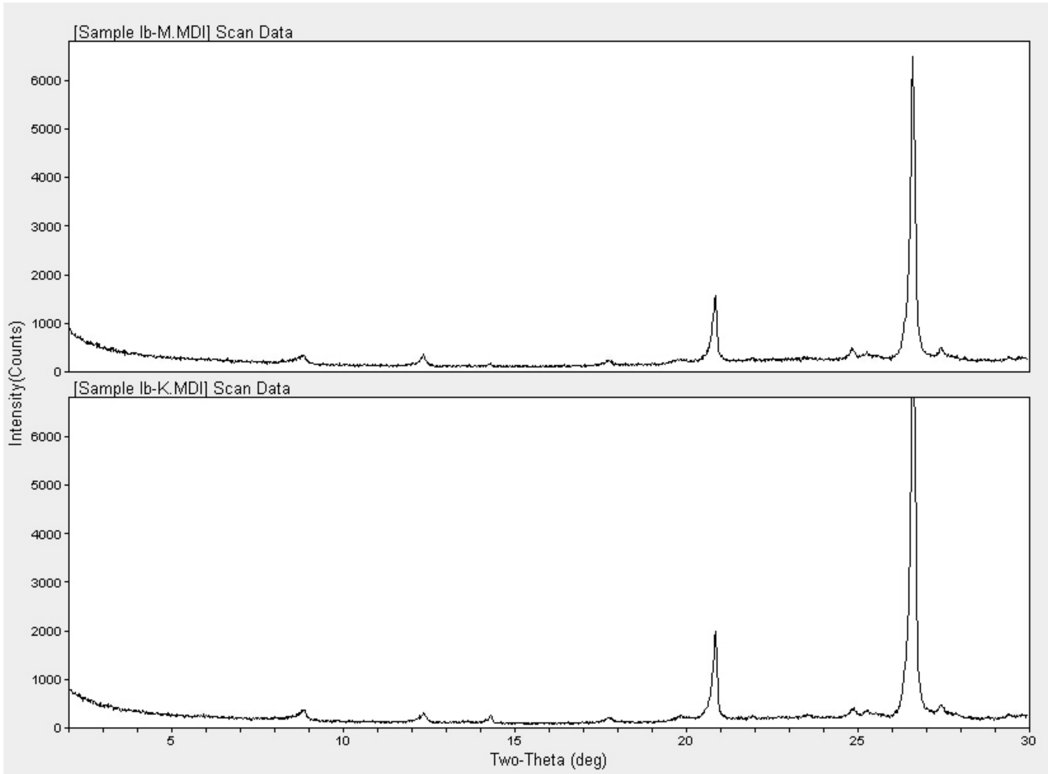
cannot be stated confidently because there were only two columns functioning during most of the study which did not allow as strong an analysis.

- The flushing effect of the larger simulated rainfalls implies that it may be possible for bacteria, viruses or emerging contaminants to reach the groundwater during recharge events. This conclusion also warrants more research.

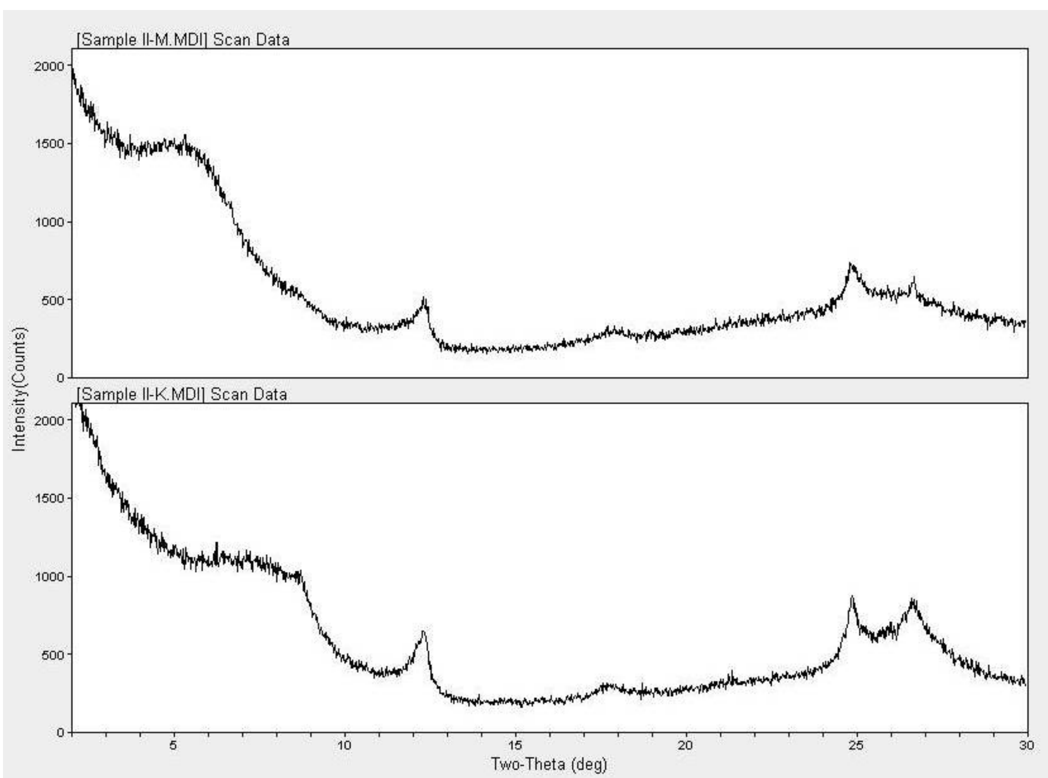
APPENDICES

APPENDIX A

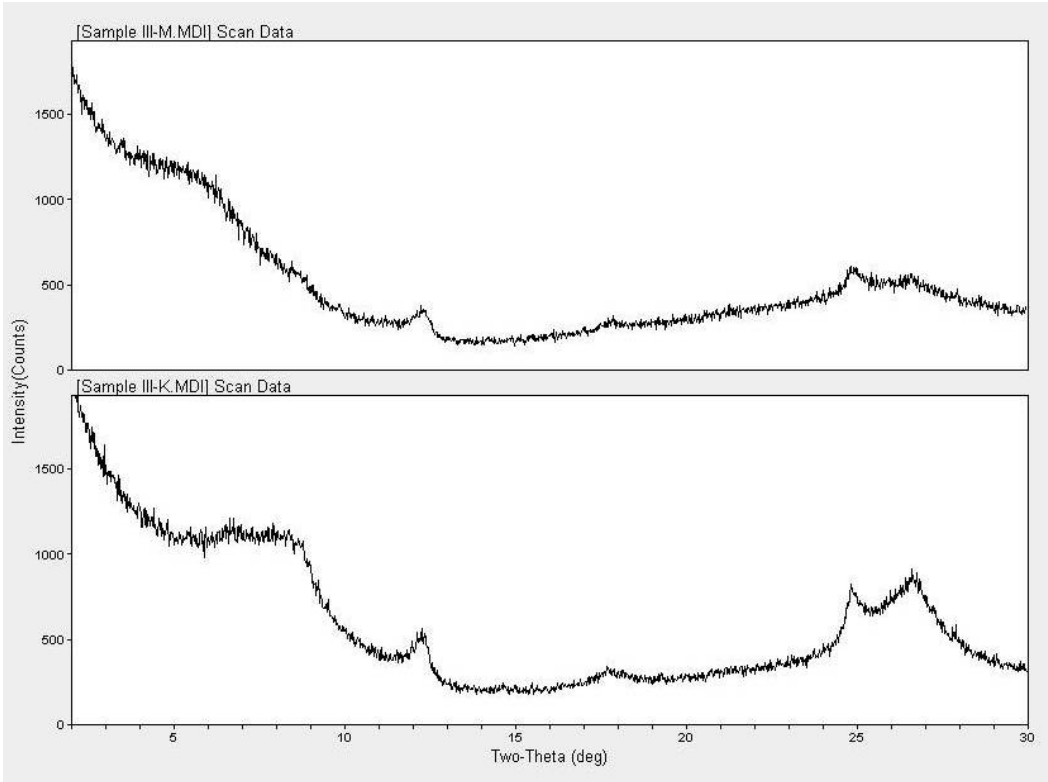
X-ray Diffractometer Graphs



A. 1, Type Ib Soil XRD Scans. Magnesium treated (above) and Potassium treated (below)



A. 2, Type II Soil XRD Scans. Magnesium treated (above) and Potassium treated (below)



A. 3, Type III Soil XRD Scans. Magnesium treated (above) and Potassium treated (below

APPENDIX B

Rain Event Data

January 29th 2007

Rain Event #1 5-Year-Two-Hour-Storm

Rain Gauge #1	3.81	cm	Target Rainfall	6.85	cm
Rain Gauge #2	6.76	cm	Actual Rainfall	6.51	cm
Rain Gauge #3	8.95	cm	% different	4.96	
Average Rain	6.51	cm			

Area of Columns 182.3 cm^3

	Type Ib			Type II			Type III			
Column Name	A	B	C	D	E	F	G	H	I	
Volume of Rain	1186	1186	1186	1186		1186	1186	1186	1186	cm^3
Run-Off Collected	140	0	510	1300		500	0	0	0	cm^3
Run-Off	11.8	0.0	43.0	109.6		42.1	0.0	0.0	0.0	%
Average Run-Off		18.3			75.9			0.0		%
Average Infiltration		81.7			24.1			100.0		%

3:27	on	4:03		4:40	off
3:28		4:04		4:41	
3:29		4:05		4:42	
3:30		4:06	on	4:43	on
3:31	off	4:07		4:44	off
3:32		4:08	off	4:45	
3:33		4:09		4:46	on
3:34		4:10	on	4:47	
3:35	on	4:11		4:48	off
3:36		4:12	off	4:49	
3:37		4:13		4:50	
3:38	off	4:14		4:51	
3:39	on	4:15	on	4:52	
3:40		4:16		4:53	
3:41	off	4:17	off	4:54	
3:42		4:18		4:55	
3:43		4:19		4:56	
3:44		4:20		4:57	
3:45		4:21	on	4:58	
3:46	on	4:22		4:59	
3:47		4:23	off	5:00	
3:48	off	4:24		5:01	on
3:49		4:26		5:02	
3:50		4:27		5:03	off
3:51		4:28	on	5:04	
3:52	on	4:29		5:05	
3:53	off	4:30	off	5:06	
3:54		4:31		5:07	on
3:55	on	4:32		5:08	
3:56		4:33		5:09	off
3:57	off	4:34		5:10	
3:58		4:35		5:11	
3:59		4:36		5:12	on
4:00	on	4:37		5:13	
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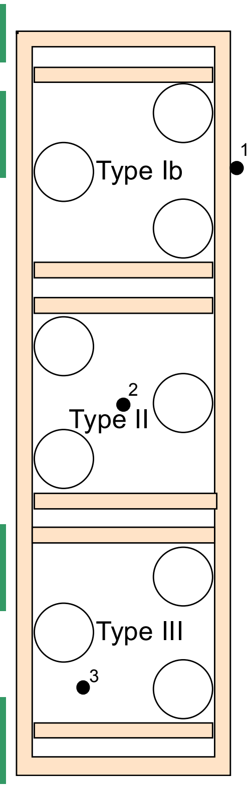


B. 1. 5-year, two-hour storm

Tuesday, 2/27/07

Rain Event #2 25-Year-Two Hour Storm

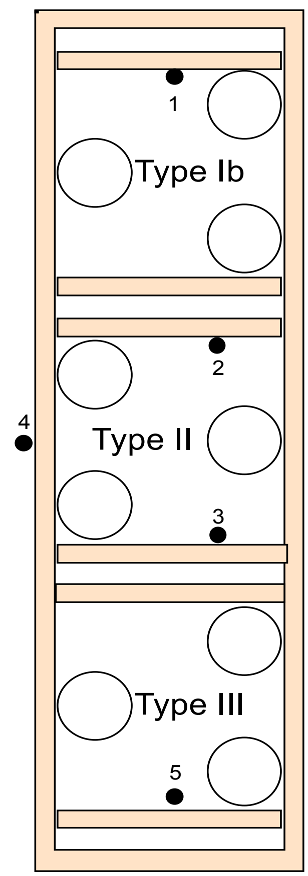
Rain Gauge #1	7.60	cm
Rain Gauge #2	9.00	cm
Rain Gauge #3	9.40	cm
Rain Gauge #4	11.18	cm
Rain Gauge #5	10.00	cm
Average	9.44	cm

Target Rainfall	9.92	cm
Actual Rainfall	9.44	cm
% difference	4.839	

Area of columns 182 cm^3

	Type Ib			Type II			Type III			
Column Name	A	B	C	D	E	F	G	H	I	
Volume of Rain	1717	1717	1717	1717		1717	1717	1717	1717	cm^3
Run-Off Collected	33	720	620	310		0	0	0	0	cm^3
Run-Off	1.9	41.9	36.1	18.1		0.0	0.0	0.0	0.0	%
Average Run-Off		26.7			9.0			0.0		%
Average Infiltration		73.3			91.0			100.0		%

9:35	on	10:14		10:52	
9:36		10:15		10:53	
9:37		10:16		10:54	
9:38		10:17		10:55	
9:39		10:18		10:56	
9:40		10:19		10:57	
9:41		10:20	off	10:58	
9:42		10:21		10:59	
9:43		10:22		11:00	
9:44		10:23		11:01	
9:45		10:24		11:02	
9:46		10:25		11:03	
9:47		10:26		11:04	
9:48		10:27		11:05	
9:49		10:28		11:06	
9:50		10:29		11:07	
9:51		10:30	on	11:08	
9:52		10:31		11:09	
9:53		10:32		11:10	
9:54		10:33		11:11	
9:55		10:34		11:12	
9:56		10:35		11:13	
9:57		10:36		11:14	
9:58		10:37		11:15	off
9:59		10:38		11:16	
10:00		10:39		11:17	
10:01		10:40		11:18	
10:02		10:41		11:19	
10:03		10:42		11:20	on
10:04		10:43		11:21	
10:05		10:44		11:22	
10:06		10:45		11:23	
10:07		10:46		11:24	
10:08		10:47		11:25	
10:09		10:48		11:26	
10:10		10:49		11:27	
10:11		10:50		11:28	
10:12		10:51		11:29	
10:13				11:30	off



B. 2. 25-year, two-hour storm

Tuesday, 3/20/07

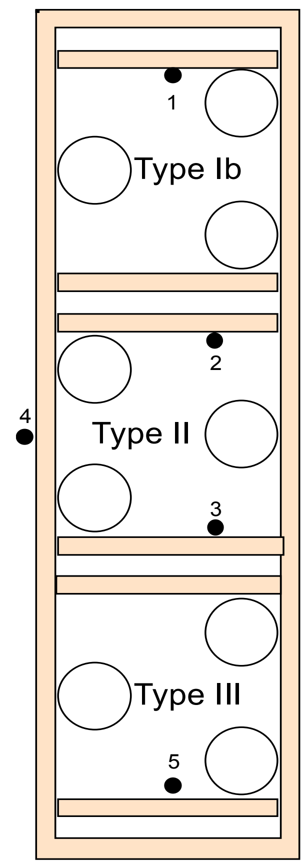
Rain Event #3 50-Year-Two Hour Storm

Rain Gauge #1	7.60	cm		Target Rainfall	11.68	cm
Rain Gauge #2	14.40	cm		Actual Rainfall	11.66	cm
Rain Gauge #3	13.00	cm				
Rain Gauge #4	13.12	cm		% difference	0.137	
Rain Gauge #5	10.20	cm				
Average	11.66	cm				

Area of columns 182 cm^3

		Type Ib			Type II			Type III	
Column Name	A	B	C	D	E	F	G	H	I	
Volume of Rain	2123	2123	2123	2123		2123	2123	2123	2123	cm^3
Run-Off Collected	1400	0	580	1180		1525	0	0	0	cm^3
Run-Off	65.9	0.0	27.3	55.6		71.8	0.0	0.0	0.0	%
Average Run-Off		31.1			63.7			0.0		%
Average Infiltration		68.9			36.3			100.0		%

10:00	on	10:40		11:20	on
10:01		10:41		11:21	
10:02		10:42		11:22	
10:03		10:43		11:23	
10:04		10:44		11:24	
10:05		10:45		11:25	
10:06		10:46		11:26	
10:07		10:47		11:27	
10:08		10:48		11:28	
10:09		10:49		11:29	
10:10		10:50		11:30	
10:11		10:51		11:31	
10:12		10:52		11:32	
10:13		10:53		11:33	
10:14		10:54	off	11:34	
10:15		10:55		11:35	
10:16		10:56		11:36	
10:17		10:57		11:37	
10:18		10:58		11:38	
10:19		10:59		11:39	
10:20		11:00		11:40	
10:21		11:01		11:41	off
10:22		11:02		11:42	
10:23		11:03		11:43	
10:24		11:04		11:44	
10:25	off	11:05	on	11:45	on
10:26		11:06		11:46	
10:27		11:07		11:47	
10:28		11:08		11:48	
10:29		11:09		11:49	
10:30	on	11:10		11:50	
10:31		11:11		11:51	
10:32		11:12		11:52	
10:33		11:13		11:53	
10:34		11:14		11:54	
10:35		11:15	off	11:55	
10:36		11:16		11:56	
10:37		11:17		11:57	
10:38		11:18		11:58	off
10:39		11:19		11:59	



B. 3 50-year, two-hour storm

APPENDIX C

Background Column Data

	Actual Concentrations (mg/L)							
	NO_3	NH_3	NO_2	CBOD	TSS	TIN	Column	Soil Type
Week 7	0.5	30.0	0.0	46.3	17.3	30.5		Septic
Week 8	4.7	29.7	0.0	58.8	16.4	34.3		Septic
Week 9	10.4	21.1	0.0	53.3	15.0	31.5		Septic
Week 10	4.3	12.8	0.0	68.8	21.6	17.1		Septic
Week 11	4.7	31.8	0.0	79.0	21.6	36.5		Septic
Week 12	4.6	29.6	0.0	57.0	22.0	34.3		Septic
Week 13	2.4	33.2	0.0	29.0	15.8	35.5		Septic
Week 14	3.4	27.7	0.0	60.7	20.7	30.2		Septic
Week 15	6.4	21.5	0.0	51.2	18.3	27.9		Septic
Week 16	7.8	21.7	0.0	58.0	22.5	29.5		Septic
Week 17	19.9	27.1	0.0	84.5	26.3	47.0		Septic
Week 18	10.4	24.3	0.0	99.3	33.8	34.7		Septic
Week 19	10.5	23.7	0.0	94.2	34.0	34.2		Septic
Week 20	9.8	25.2	0.0	111.0	35.3	35.0		Septic
Week 21	11.8	30.3	0.0	89.7	37.7	40.2		Septic
Week 22	19.3	33.0	0.0	99.7	37.2	52.4		Septic
Week 23	12.8	25.5	0.0	62.0	21.2	38.3		Septic
Week 24	4.8	34.5	0.0	39.0	18.8	39.3		Septic
Week 25	5.7	20.7	6.2	28.2	13.2	32.6		Septic

	Actual Concentrations (mg/L)							
	NO_3	NH_3	NO_2	CBOD	TSS	TIN	Column	Soil Type
Week 7	1.2	31.7	0.3	3.5	1.6	33.2	A	Type Ib
Week 8	4.9	27.9	0.7	2.9	1.8	33.0	A	Type Ib
Week 9	2.0	19.7	0.1	7.1	1.8	21.8	A	Type Ib
Week 10	0.0	12.7	0.0	12.0	12.3	12.7	A	Type Ib
Week 11	0.1	37.0	0.0	11.1	25.8	37.1	A	Type Ib
Week 12	0.0	31.7	0.0	16.6	16.3	31.7	A	Type Ib
Week 13	0.0	41.2	0.0	5.7	17.5	41.2	A	Type Ib
Week 14	0.0	33.1	0.0	7.4	12.3	33.1	A	Type Ib
Week 15	0.0	38.5	0.0	6.4	0.7	38.5	A	Type Ib
Week 16	0.7	35.4	0.0	6.1	12.6	36.1	A	Type Ib
Week 17	1.6	35.6	0.0	.	.	37.2	A	Type Ib
Week 18	0.0	26.5	0.0	7.5	17.5	26.5	A	Type Ib
Week 19	.	.	.	.	.	.	A	Type Ib
Week 20	0.4	27.1	0.0	.	.	27.5	A	Type Ib
Week 21	0.0	25.1	0.0	.	.	25.1	A	Type Ib
Week 22	0.1	31.3	0.0	.	.	31.4	A	Type Ib
Week 23	0.0	31.2	0.0	2.4	12.1	31.2	A	Type Ib
Week 24	0.0	36.5	0.0	.	.	36.5	A	Type Ib
Week 25	1.0	27.8	0.1	2.3	2.5	28.9	A	Type Ib

	Actual Concentrations (mg/L)							
	NO_3	NH_3	NO_2	CBOD	TSS	TIN	Column	Soil Type
Week 7	1.0	34.0	0.2	6.0	2.0	35.2	B	Type Ib
Week 8	1.9	20.7	0.1	3.2	0.7	22.6	B	Type Ib
Week 9	5.3	18.1	0.4	2.8	0.8	23.6	B	Type Ib
Week 10	1.8	12.8	0.6	3.8	5.5	15.2	B	Type Ib
Week 11	2.8	23.6	0.1	4.2	2.5	26.5	B	Type Ib
Week 12	0.2	24.1	0.1	4.6	1.2	24.3	B	Type Ib
Week 13	1.4	38.2	0.2	1.7	0.9	39.8	B	Type Ib
Week 14	1.2	29.2	0.2	7.1	0.8	30.6	B	Type Ib
Week 15	2.9	40.1	0.1	13.2	4.3	43.1	B	Type Ib
Week 16	0.6	31.8	0.1	5.4	12.3	32.5	B	Type Ib
Week 17	6.5	28.2	0.1	8.9	.	34.8	B	Type Ib
Week 18	0.2	21.8	0.0	35.1	7.2	22.0	B	Type Ib
Week 19	.	.	.	.	.	.	B	Type Ib
Week 20	0.1	26.5	0.0	9.6	37.0	26.7	B	Type Ib
Week 21	0.0	33.4	0.0	45.6	14.0	33.4	B	Type Ib
Week 22	3.1	33.0	0.0	7.2	18.5	36.1	B	Type Ib
Week 23	0.6	28.9	0.1	11.1	20.4	29.6	B	Type Ib
Week 24	4.0	31.2	0.6	0.4	16.0	35.8	B	Type Ib
Week 25	7.8	28.3	2.5	2.4	4.8	38.6	B	Type Ib

	Actual Concentrations (mg/L)							
	NO_3	NH_3	NO_2	CBOD	TSS	TIN	Column	Soil Type
Week 7	1.0	28.6	0.2	6.5	2.0	29.8	C	Type Ib
Week 8	0.7	27.0	0.0	8.4	1.8	27.7	C	Type Ib
Week 9	0.9	15.7	0.0	3.9	3.1	16.6	C	Type Ib
Week 10	1.4	22.2	0.0	5.6	0.9	23.6	C	Type Ib
Week 11	0.8	33.9	0.0	5.3	5.7	34.7	C	Type Ib
Week 12	2.7	27.0	0.0	2.9	13.6	29.7	C	Type Ib
Week 13	3.4	37.5	0.0	1.4	1.3	40.9	C	Type Ib
Week 14	0.4	29.1	0.0	2.6	1.2	29.6	C	Type Ib
Week 15	4.0	38.8	0.0	31.7	15.3	42.8	C	Type Ib
Week 16	0.3	31.9	0.0	18.9	10.6	32.2	C	Type Ib
Week 17	0.0	32.8	0.0	7.5	.	32.8	C	Type Ib
Week 18	0.3	22.2	0.0	10.1	21.1	22.5	C	Type Ib
Week 19	.	.	.	.	.	.	C	Type Ib
Week 20	2.6	27.7	0.0	3.5	.	18.2	C	Type Ib
Week 21	1.9	31.4	0.0	14.9	4.0	33.3	C	Type Ib
Week 22	0.0	35.7	0.0	8.4	25.0	35.7	C	Type Ib
Week 23	0.0	31.5	0.0	6.9	22.9	31.5	C	Type Ib
Week 24	0.0	31.3	0.0	0.6	4.0	31.3	C	Type Ib
Week 25	0.0	29.8	0.0	1.6	2.5	29.8	C	Type Ib

	Actual Concentrations (mg/L)							
	NO_3	NH_3	NO_2	CBOD	TSS	TIN	Column	Soil Type
Week 7	1.0	6.8	0.2	4.0	2.0	8.0	D	Type II
Week 8	0.9	9.0	0.0	2.2	0.4	9.9	D	Type II
Week 9	3.3	8.6	0.0	3.3	0.4	12.0	D	Type II
Week 10	2.4	11.0	0.0	3.6	0.6	13.4	D	Type II
Week 11	0.3	16.1	0.0	11.8	2.5	16.4	D	Type II
Week 12	0.4	14.6	0.0	9.0	3.2	14.9	D	Type II
Week 13	0.9	18.9	0.0	3.8	4.2	19.8	D	Type II
Week 14	0.1	16.6	0.0	7.6	3.7	21.2	D	Type II
Week 15	8.0	19.6	0.0	22.7	5.2	27.6	D	Type II
Week 16	0.2	19.8	0.0	4.0	3.5	20.0	D	Type II
Week 17	2.8	22.4	0.0	4.6	.	25.2	D	Type II
Week 18	0.0	20.8	0.0	18.3	7.6	20.8	D	Type II
Week 19	.	.	.	.	.	.	D	Type II
Week 20	1.9	22.9	0.0	4.3	.	24.8	D	Type II
Week 21	1.9	27.7	0.0	4.7	12.0	29.6	D	Type II
Week 22	0.5	30.6	0.0	2.3	7.0	31.1	D	Type II
Week 23	1.2	26.7	0.0	9.6	16.6	27.9	D	Type II
Week 24	0.0	28.9	0.0	8.9	11.0	28.9	D	Type II
Week 25	4.9	23.0	0.0	7.0	13.2	27.9	D	Type II

	Actual Concentrations (mg/L)							
	NO_3	NH_3	NO_2	CBOD	TSS	TIN	Column	Soil Type
Week 7	1.0	4.1	0.2	5.5	12.8	5.3	F	Type II
Week 8	0.0	7.0	0.0	5.7	16.3	7.0	F	Type II
Week 9	0.0	6.9	0.0	4.8	14.6	6.9	F	Type II
Week 10	1.8	7.7	0.0	7.4	15.8	9.5	F	Type II
Week 11	0.7	16.9	0.0	12.7	15.3	17.6	F	Type II
Week 12	1.3	15.7	0.0	19.7	12.5	17.0	F	Type II
Week 13	1.3	21.5	0.0	5.5	9.5	22.7	F	Type II
Week 14	0.0	18.4	0.0	6.9	10.8	25.2	F	Type II
Week 15	7.7	30.5	0.0	21.4	15.0	38.2	F	Type II
Week 16	0.1	21.4	0.0	6.0	13.9	21.5	F	Type II
Week 17	0.0	23.2	0.0	3.1	.	23.2	F	Type II
Week 18	0.0	21.7	0.0	35.2	11.5	21.7	F	Type II
Week 19	.	21.9	.	.	.	.	F	Type II
Week 20	2.3	24.3	0.0	10.6	.	26.6	F	Type II
Week 21	2.3	29.5	0.0	10.5	14.0	31.8	F	Type II
Week 22	0.0	38.0	0.0	2.7	23.0	38.0	F	Type II
Week 23	0.0	28.8	0.0	3.9	15.8	28.8	F	Type II
Week 24	0.0	30.0	0.0	0.4	11.0	30.0	F	Type II
Week 25	0.0	26.2	0.0	2.7	11.1	26.2	F	Type II

	Actual Concentrations (mg/L)							
	NO_3	NH_3	NO_2	CBOD	TSS	TIN	Column	Soil Type
Week 7	17.7	0.1	0.2	2.0	2.0	18.1	G	Type III
Week 8	10.9	0.1	0.0	0.4	0.3	11.0	G	Type III
Week 9	6.7	0.0	0.0	.	.	6.7	G	Type III
Week 10	8.2	0.1	0.0	3.1	1.3	8.2	G	Type III
Week 11	16.1	0.1	0.0	0.5	0.9	16.2	G	Type III
Week 12	22.1	0.3	0.0	0.5	1.1	22.4	G	Type III
Week 13	12.8	0.1	0.0	0.0	2.3	12.9	G	Type III
Week 14	11.7	0.3	0.0	0.4	2.3	11.9	G	Type III
Week 15	11.0	0.1	0.0	1.0	0.8	11.1	G	Type III
Week 16	10.6	0.1	0.0	0.3	1.3	10.7	G	Type III
Week 17	10.0	0.1	0.0	0.0	.	10.1	G	Type III
Week 18	8.9	0.0	0.0	0.4	1.4	8.9	G	Type III
Week 19	.	0.1	.	.	.	.	G	Type III
Week 20	6.4	0.0	0.0	0.1	.	6.4	G	Type III
Week 21	10.2	0.0	0.0	.	.	10.3	G	Type III
Week 22	11.2	0.0	0.0	.	15.3	11.2	G	Type III
Week 23	10.9	0.1	0.1	.	11.6	11.0	G	Type III
Week 24	10.8	0.3	0.0	.	.	11.1	G	Type III
Week 25	3.3	0.0	0.0	0.0	.	3.3	G	Type III

	Actual Concentrations (mg/L)							
	NO_3	NH_3	NO_2	CBOD	TSS	TIN	Column	Soil Type
Week 7	18.0	0.1	0.2	2.0	2.0	18.3	H	Type III
Week 8	8.7	0.0	0.0	0.3	0.7	8.8	H	Type III
Week 9	7.6	0.0	0.0	.	.	7.6	H	Type III
Week 10	7.8	0.0	0.0	0.4	1.8	7.9	H	Type III
Week 11	14.6	0.1	0.0	0.3	1.1	14.7	H	Type III
Week 12	14.9	0.1	0.0	0.4	1.6	15.0	H	Type III
Week 13	14.6	0.3	0.0	0.0	6.1	14.9	H	Type III
Week 14	12.1	0.1	0.0	0.4	6.0	12.2	H	Type III
Week 15	11.7	0.1	0.0	0.5	0.6	11.8	H	Type III
Week 16	8.2	0.1	0.0	0.3	1.7	8.3	H	Type III
Week 17	11.0	0.0	0.0	0.0	.	11.0	H	Type III
Week 18	8.3	0.0	0.0	0.3	1.0	8.4	H	Type III
Week 19	.	0.1	.	.	.	.	H	Type III
Week 20	8.9	0.0	0.0	0.0	.	8.9	H	Type III
Week 21	8.8	0.0	0.0	.	.	8.8	H	Type III
Week 22	10.3	0.1	0.0	.	5.3	10.4	H	Type III
Week 23	9.7	0.1	0.0	.	3.6	9.8	H	Type III
Week 24	10.0	0.0	0.0	.	.	10.0	H	Type III
Week 25	4.7	0.0	0.0	0.0	.	4.8	H	Type III

	Actual Concentrations (mg/L)							
	NO_3	NH_3	NO_2	CBOD	TSS	TIN	Column	Soil Type
Week 7	18.3	0.1	0.2	2.0	2.5	18.6	I	Type III
Week 8	12.7	0.0	0.0	0.2	0.5	12.7	I	Type III
Week 9	10.4	0.0	0.0	.	.	10.4	I	Type III
Week 10	10.4	0.0	0.0	0.3	5.3	10.5	I	Type III
Week 11	13.9	0.1	0.0	0.3	4.3	14.0	I	Type III
Week 12	19.8	0.0	0.0	0.4	2.6	19.8	I	Type III
Week 13	11.5	0.2	0.0	0.0	2.7	11.7	I	Type III
Week 14	12.0	0.1	0.0	0.2	2.2	12.1	I	Type III
Week 15	9.8	0.1	0.0	1.0	0.6	10.9	I	Type III
Week 16	10.6	0.1	0.0	0.2	1.0	10.9	I	Type III
Week 17	10.8	0.0	0.0	0.0	.	10.8	I	Type III
Week 18	10.4	0.0	0.0	0.2	1.1	10.4	I	Type III
Week 19	.	0.1	.	.	.	.	I	Type III
Week 20	11.5	0.0	0.0	0.0	.	11.5	I	Type III
Week 21	11.7	0.1	0.0	.	.	11.8	I	Type III
Week 22	14.0	0.2	0.0	.	5.7	14.2	I	Type III
Week 23	14.9	0.0	0.0	.	6.9	14.9	I	Type III
Week 24	13.3	0.0	0.0	.	.	13.3	I	Type III
Week 25	5.5	0.0	0.0	.	.	5.5	I	Type III

C. 1. Weekly mean concentrations

	% removal from Septic				
	CBOD	TSS	TIN	Column	Soil Type
Week 7	92.4	90.8	-8.9	A	Type Ib
Week 8	95.1	89.0	3.8	A	Type Ib
Week 9	86.7	88.0	30.8	A	Type Ib
Week 10	82.6	43.1	25.7	A	Type Ib
Week 11	85.9	-19.4	-1.6	A	Type Ib
Week 12	70.9	25.9	7.6	A	Type Ib
Week 13	80.3	-10.8	-16.1	A	Type Ib
Week 14	87.8	40.6	-9.6	A	Type Ib
Week 15	87.5	96.2	-38.0	A	Type Ib
Week 16	89.5	44.0	-22.4	A	Type Ib
Week 17			20.9	A	Type Ib
Week 18	92.4	48.2	23.6	A	Type Ib
Week 19				A	Type Ib
Week 20			21.4	A	Type Ib
Week 21			37.6	A	Type Ib
Week 22			40.1	A	Type Ib
Week 23	96.1	42.9	18.5	A	Type Ib
Week 24			7.1	A	Type Ib
Week 25	91.8	81.1	11.3	A	Type Ib

	% removal from Septic				
	CBOD	TSS	TIN	Column	Soil Type
Week 7	87.0	88.4	-15.4	B	Type Ib
Week 8	94.6	95.7	34.1	B	Type Ib
Week 9	94.7	94.7	25.1	B	Type Ib
Week 10	94.5	74.5	11.1	B	Type Ib
Week 11	94.7	88.4	27.4	B	Type Ib
Week 12	91.9	94.5	29.2	B	Type Ib
Week 13	94.1	94.3	-12.1	B	Type Ib
Week 14	88.3	96.1	-1.3	B	Type Ib
Week 15	74.2	76.5	-54.5	B	Type Ib
Week 16	90.7	45.3	-10.2	B	Type Ib
Week 17	89.5		26.0	B	Type Ib
Week 18	64.7	78.7	36.6	B	Type Ib
Week 19				B	Type Ib
Week 20	91.4	-4.8	23.7	B	Type Ib
Week 21	49.2	62.9	16.9	B	Type Ib
Week 22	92.8	50.3	31.1	B	Type Ib
Week 23	82.1	3.8	22.7	B	Type Ib
Week 24	99.0	14.9	8.9	B	Type Ib
Week 25	91.5	63.6	-18.4	B	Type Ib

	% removal from Septic				
	CBOD	TSS	TIN	Column	Soil Type
Week 7	86.0	88.4	2.3	C	Type Ib
Week 8	85.7	89.0	19.2	C	Type Ib
Week 9	92.7	79.3	47.3	C	Type Ib
Week 10	91.9	95.8	-38.0	C	Type Ib
Week 11	93.3	73.6	4.9	C	Type Ib
Week 12	94.9	38.2	13.4	C	Type Ib
Week 13	95.2	91.8	-15.2	C	Type Ib
Week 14	95.7	94.2	2.0	C	Type Ib
Week 15	38.1	16.4	-53.4	C	Type Ib
Week 16	67.4	52.9	-9.2	C	Type Ib
Week 17	91.1		30.2	C	Type Ib
Week 18	89.8	37.6	35.2	C	Type Ib
Week 19				C	Type Ib
Week 20	96.8		48.0	C	Type Ib
Week 21	83.4	89.4	17.2	C	Type Ib
Week 22	91.6	32.8	31.9	C	Type Ib
Week 23	88.9	-8.0	17.8	C	Type Ib
Week 24	98.5	78.7	20.4	C	Type Ib
Week 25	94.3	81.1	8.6	C	Type Ib

	% removal from Septic				
	CBOD	TSS	TIN	Column	Soil Type
Week 7	91.4	88.4	73.8	D	Type II
Week 8	96.3	97.6	71.1	D	Type II
Week 9	93.8	97.3	61.9	D	Type II
Week 10	94.8	97.2	21.6	D	Type II
Week 11	85.1	88.4	55.1	D	Type II
Week 12	84.2	85.5	56.6	D	Type II
Week 13	86.9	73.4	44.2	D	Type II
Week 14	87.5	82.1	29.8	D	Type II
Week 15	55.7	71.6	1.1	D	Type II
Week 16	93.1	84.4	32.2	D	Type II
Week 17	94.6		46.4	D	Type II
Week 18	81.6	77.5	40.1	D	Type II
Week 19				D	Type II
Week 20	96.1		29.1	D	Type II
Week 21	94.8	68.2	26.4	D	Type II
Week 22	97.7	81.2	40.6	D	Type II
Week 23	84.5	21.7	27.2	D	Type II
Week 24	77.2	41.5	26.5	D	Type II
Week 25	75.2	0.0	14.4	D	Type II

	% removal from Septic				
	CBOD	TSS	TIN	Column	Soil Type
Week 7	88.1	26.0	82.6	F	Type II
Week 8	90.3	0.6	79.6	F	Type II
Week 9	91.0	2.7	78.1	F	Type II
Week 10	89.2	26.9	44.4	F	Type II
Week 11	83.9	29.2	51.8	F	Type II
Week 12	65.4	43.2	50.4	F	Type II
Week 13	81.0	39.9	36.1	F	Type II
Week 14	88.6	47.8	16.6	F	Type II
Week 15	58.2	18.0	-36.9	F	Type II
Week 16	89.7	38.2	27.1	F	Type II
Week 17	96.3		50.6	F	Type II
Week 18	64.6	66.0	37.5	F	Type II
Week 19				F	Type II
Week 20	90.5		24.0	F	Type II
Week 21	88.3	62.9	20.9	F	Type II
Week 22	97.3	38.2	27.5	F	Type II
Week 23	93.7	25.5	24.8	F	Type II
Week 24	99.0	41.5	23.7	F	Type II
Week 25	90.4	15.9	19.6	F	Type II

	% removal from Septic				
	CBOD	TSS	TIN	Column	Soil Type
Week 7	95.7	88.4	40.7	G	Type III
Week 8	99.3	98.2	67.9	G	Type III
Week 9			78.7	G	Type III
Week 10	95.5	94.0	52.0	G	Type III
Week 11	99.4	95.8	55.6	G	Type III
Week 12	99.1	95.0	34.7	G	Type III
Week 13	100.0	85.4	63.7	G	Type III
Week 14	99.3	88.9	60.6	G	Type III
Week 15	98.0	95.6	60.2	G	Type III
Week 16	99.5	94.2	63.7	G	Type III
Week 17	100.0		78.5	G	Type III
Week 18	99.6	95.9	74.4	G	Type III
Week 19				G	Type III
Week 20	99.9		81.7	G	Type III
Week 21			74.4	G	Type III
Week 22		58.9	78.6	G	Type III
Week 23		45.3	71.3	G	Type III
Week 24			71.8	G	Type III
Week 25	100.0		89.9	G	Type III

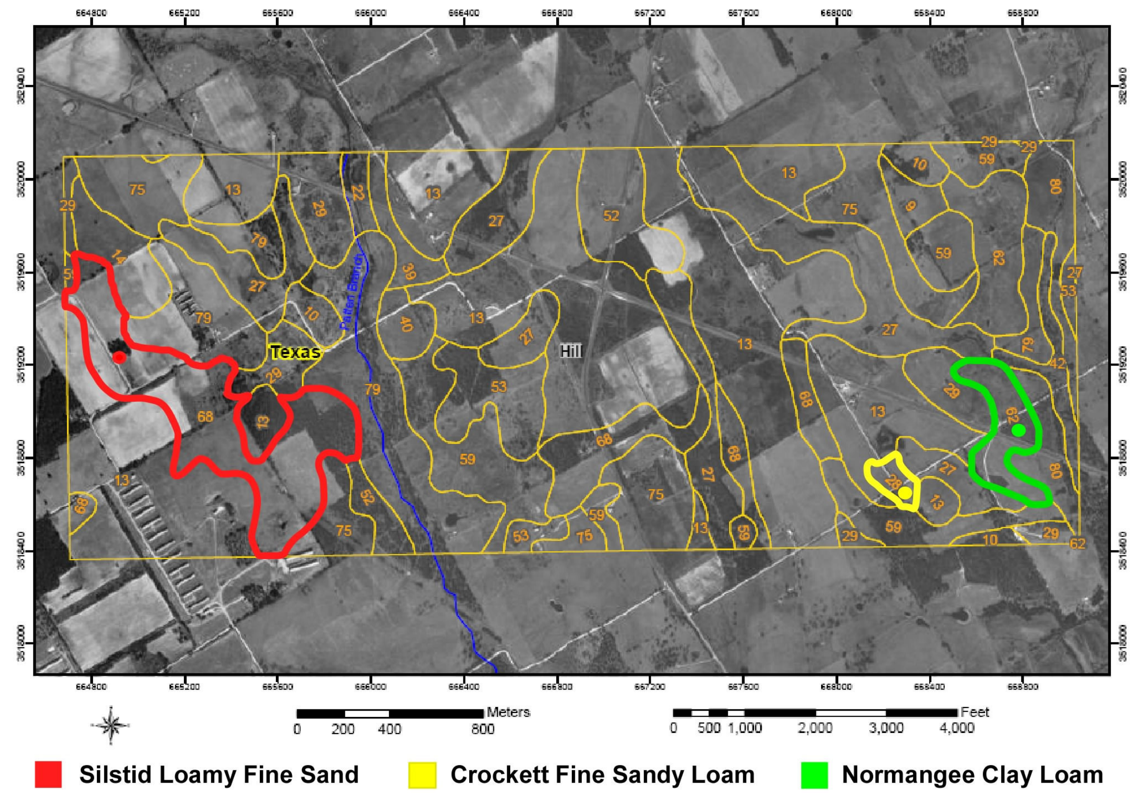
	% removal from Septic				
	CBOD	TSS	TIN	Column	Soil Type
Week 7	95.7	88.4	40.0	H	Type III
Week 8	99.5	95.7	74.3	H	Type III
Week 9			75.9	H	Type III
Week 10	99.4	91.7	53.8	H	Type III
Week 11	99.6	94.9	59.7	H	Type III
Week 12	99.3	92.7	56.3	H	Type III
Week 13	100.0	61.4	58.0	H	Type III
Week 14	99.3	71.0	59.6	H	Type III
Week 15	99.0	96.7	57.7	H	Type III
Week 16	99.5	92.4	71.9	H	Type III
Week 17	100.0		76.6	H	Type III
Week 18	99.7	97.0	75.8	H	Type III
Week 19				H	Type III
Week 20	100.0		74.6	H	Type III
Week 21			78.1	H	Type III
Week 22		85.8	80.2	H	Type III
Week 23		83.0	74.4	H	Type III
Week 24			74.6	H	Type III
Week 25	100.0		85.3	H	Type III

	% removal from Septic				
	CBOD	TSS	TIN	Column	Soil Type
Week 7	95.7	85.5	39.0	I	Type III
Week 8	99.7	97.0	63.0	I	Type III
Week 9			67.0	I	Type III
Week 10	99.6	75.5	38.6	I	Type III
Week 11	99.6	80.1	61.6	I	Type III
Week 12	99.3	88.2	42.3	I	Type III
Week 13	100.0	82.9	67.0	I	Type III
Week 14	99.7	89.4	59.9	I	Type III
Week 15	98.0	96.7	60.9	I	Type III
Week 16	99.7	95.6	63.1	I	Type III
Week 17	100.0		77.0	I	Type III
Week 18	99.8	96.7	70.0	I	Type III
Week 19				I	Type III
Week 20	100.0		67.1	I	Type III
Week 21			70.6	I	Type III
Week 22		84.7	72.9	I	Type III
Week 23		67.5	61.1	I	Type III
Week 24			66.2	I	Type III
Week 25			83.1	I	Type III

C. 2. Percent removal by soil type

APPENDIX D

Soil Sample Locations



D. 1 Specific locations of soil samples (near the intersection of fm 933 and fm 2114, west of the town West)

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