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ON-SITE DOMESTIC WASTEWATER RENOVATION UTILIZING A PARTIALLY SATURATED RECIRCULATING SAND FILTER WITH LAWN IRRIGATION OF EFFLUENT

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ABSTRACT

A prototype on-site domestic wastewater renovation system was installed in 1988 and monitored during the period of February 1988 to November 1988. The prototype system used a partially saturated recirculating sand filter for renovation and a lawn irrigation sprinkler for distribution of renovated wastewater. The prototype was evaluated on the basis of its ability to remove nitrogen, COD, and coliform bacteria. A lawn plot receiving renovated wastewater, a potable-water irrigated plot and a dry control plot were sampled to evaluate the potential environmental impact of applying renovated wastewater to a lawn.

Water quality samples were collected weekly from various points within the prototype system. Runoff samples were collected from the lawn plots whenever natural precipitation events produced runoff. All water samples were analyzed for the concentration of nitrogen, COD, and coliform bacteria. Seasonal grass samples from the plots were checked for coliform bacterial content in an attempt to assess the potential for human exposure to pathogens by contact with and/or ingestion of lawn grass.

The investigation showed that the prototype had removal efficiencies as high as 82.5% for nitrogen, 96.3% for COD, and log reductions of 2.8 and 2.4 for fecal and total coliforms, respectively. Statistical comparisons of bacterial exposure, runoff water quality and grass yield

among each of the plots showed few significant adverse differences when comparing the plot receiving renovated wastewater to the irrigated and dry control plots.

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1.0 INTRODUCTION

Conventional on-site domestic wastewater renovation systems utilize the physical, chemical, and biological properties of soil to remove waste material as it flows downward through the profile. Many sites suitable for development have insufficient soil depth or poor soil characteristics, and therefore cannot be relied upon to adequately renovate domestic wastewater. Alternative systems such as at-grade soil absorption systems, and mound systems alleviate some of the problem with insufficient depth, however, there are many sites which do not have well developed soils required by these systems.

Sites without adequate soil require a system which can adequately renovate the wastewater, within a closed system, and apply the effluent onto the soil surface to percolate to the groundwater. Recirculating sand filters have significant potential for use as a non-soil based renovation component for on-site systems. Recirculating sand filter systems may, with proper design and management, achieve significant removal of nitrogen, organics, and coliform bacteria.

Application of effluent from recirculating sand filter systems onto lawn surfaces for final disposal has many advantages, however, more research is needed to satisfy all concerns about health risks from such a practice. To accomplish this research a system must be studied to determine the effects of applying renovated wastewater to a lawn surface.

As shown in the following literature review, there has been significant research on recirculating filters, but very few authors have addressed the issue concerning the disposal of treated effluent. Most research has dealt primarily with optimizing the removal of one particular waste constituent at the expense of others. The purpose of this project was to observe a prototype recirculating sand filter system and evaluate its performance with respect to nitrogen, organics, and bacterial removal; while also observing the environmental impact associated with the application of renovated wastewater to a lawn surface.

2.0 REVIEW OF LITERATURE

On-Site domestic waste disposal has traditionally been accomplished with a septic tank/soil absorption system. As of 1980, about 25% of the new homes constructed in the United States utilized septic tank soil absorption systems for wastewater renovation and disposal (EPA, 1980). These systems rely on separation of solids from the wastewater in the septic tank prior to the absorption and further treatment of the wastewater in the soil. Because of this, the septic tank/soil absorption system can only be installed on sites which have adequate drainage, soil structure and depth to groundwater (EPA, 1980).

Problems which can lead to septic system failure generally include high water tables, shallow or impermeable soils, highly permeable soils, or poor system design, installation and maintenance (Carlile, 1985). Mote and Griffis (1985) cited insufficient depth and unsatisfactory hydraulic conductivity as two soil characteristics which limit the utilization of conventional septic tank filter fields for on-site domestic wastewater renovation.

2.1 INNOVATIVE DESIGNS TO OVERCOME SOIL LIMITATIONS

Some soil limitations can be overcome by a number of design innovations. Example innovative systems include low pressure pipe (LPP), at-grade, mounds and soil drains for water table suppression. These systems have been presented by numerous researchers as alternative methods to overcome the problems associated with inadequate soil profiles.

Low pressure pipe systems, which provide uniform distribution of septic tank effluent (Cogger et al., 1982), have been utilized in areas having: soils with seasonally shallow or perched groundwater; soils with hydraulically restrictive horizons at shallow depths; sandy soils with rapid permeability; and sites with steep slopes (Hargett, 1985). In areas with shallow soils, LPP systems have been installed partially or totally in fill material to utilize the full soil depth (Hargett, 1985).

At-grade soil absorption systems have been developed to overcome limitations resulting from insufficient soil depths by placing the bottom of the aggregate layer "at-grade" or on the tilled soil surface (Converse et al., 1988). Insufficient soil depth limitations can be overcome in some cases by changing the design to keep more of the natural soil below the bottom of the seepage trench (Mote, 1985). Installation and use of at-grade systems have been targetted for sites where soils will not allow conventional in-ground units but have sufficient depth if it is all utilized (Mote, 1985, Converse et al., 1987).

Mound systems are above grade septic tank-soil absorption systems which rely on sand fill and natural soil at the site to renovate wastewater (Bouma et al., 1975). In order for the mound system to operate effectively the hydraulic load entering the mound must be accepted by the soil below the mound or hydraulic failure will occur (Converse and Tyler, 1985).

High water tables can limit the use of soil absorption systems; however, they can be artificially lowered to permit use of such systems. Curtain drains and underdrains are generally used to lower perched water tables. Where the perched water moves laterally, curtain drains are placed upstream of the absorption area to intercept the groundwater as it flows toward the filter area (EPA, 1980). Underdrains are used on sites where water tables exist 1.2 to 1.5 m below the ground level in permeable soils (EPA, 1980). The drains are constructed by excavating a trench and placing a perforated drainage pipe in the bottom. The underdrains are placed near the absorption field, and several drains may be necessary to sufficiently lower the water table (EPA, 1980). Depth and spacing are determined by the soil and water table characteristics.

Traditional septic systems, as well as the innovative systems mentioned previously, rely on native soils to renovate wastewater before it enters the groundwater. These systems require some minimal amount of soil to be effective. Numerous areas in Tennessee have either shallow soil depths to bedrock or rock outcrops which negate the use of these wastewater renovation systems. For example, Rutherford County, Tennessee has 59.4% (591,253 hectares, 239,280 acres) of its land area characterized by shallow soils and rock outcrops, or shallow depths to water tables (Rutherford County Soil Survey, 1977). In order for on-site domestic wastewater renovation systems to be effective on such soils a system which does not require well developed soils must be utilized. The wastewater renovation must be accomplished within a system that discharges an effluent which will not be harmful to the environment without further treatment. One system that may have potential for meeting this requirement is the recirculating sand filter (RSF).

2.2 RECIRCULATING SAND FILTERS FOR ON-SITE DOMESTIC WASTEWATER RENOVATION

The recirculating sand filter developed by Hines and Favreau (1975) consisted of a septic tank, recirculation tank and an open sand filter. The septic tank was a standard 2,840-liter (750 gallon) tank generally specified for use with conventional subsurface absorption systems. The recirculation tank provided storage of the septic discharge and the recycled sand filter effluent between pumping cycles. The recirculation tank size was suggested by Hines and Favreau (1975) to be at least equal to the capacity of the septic tank. The filter discharge line passed through the recirculation tank and was equipped with a rubber ball float valve arrangement (Hines and Favreau, 1975). This arrangement allowed a portion of the filtered effluent to pass through the recirculation tank, and the remainder was deposited in the tank to be recirculated.

For single family dwellings, Hines and Favreau (1975) suggested a recirculation pump capacity of 19 to 38 liters (5 to 10 gallons) per minute to provide a recirculation rate of approximately 4 to 1 based on raw sewage volume. The optimum pumping cycle in their studies was considered to be 10 minutes on and 20 minutes off each half hour for a total pumping time of 480 minutes per day.

The sand filter used by Hines and Favreau (1975) consisted of approximately 1 meter (3 feet) of coarse filter sand with effective size of 0.6 to 1.0 millimeters and coefficient of uniformity of less than 2.5. Approximately 30 cm (12 inches) of graded gravel was placed beneath the sand to surround a single underdrain.

The surface area for a filter serving a single family dwelling was based on 122.2 liters of raw sewage per day per square meter (3 gallons per day per square foot) of surface area. For raw sewage flows less than 1,135 liters (300 gallons) per day, Hines and Favreau (1975) stated that a minimum surface area of 9.3 square meters (100 square feet) should be provided.

Hines and Favreau (1975) have shown that these recirculating sand filter systems have consistently provided effluents of such quality that, with disinfection, the local and state regulatory agency effluent standards were satisfied. Hines and Favreau (1975) collected sand filter effluent over the period from October 1969 to February 1970 and found it to have average BOD and total suspended solids (TSS) contents of 4 mg/l (range 1 to 7 mg/l) and 5 mg/l (range 1 to 18 mg/l), respectively. The fecal coliform counts were reported as an average of 10,700 CFU's/100 ml with a range of 800 to 42,000 CFU's/100ml. Values for nitrogen were not reported for the study conducted by Hines and Favreau (1975).

The recommendations set forth by Hines and Favreau (1975) have prompted numerous studies which were performed in an attempt to optimize the basic recirculating sand filter system. Louden et al. (1985) constructed two such systems in Michigan. Both systems were constructed using the guidelines suggested by Hines and Favreau (1975) and involved subsurface discharge of the effluent to soil absorption following sand filter treatment.

One improvement made by Louden et al. (1985) was in the distribution manifold located in the sand filter. They used sprinklers consisting of 3mm (1/8 in) orifices in PVC pipe with a standard mesh window screen attached 50 mm (2 in) above the holes to distribute the effluent on the sand surface. The mesh deflector above the holes provided stream break-up during operation and produced a nonpoint source load for the filter. Therefore, a larger percentage of the filter surface area was loaded, thus increasing the projected life of the filter.

Odor has been a concern with above ground wastewater systems. Intermittent sand filters produced considerable odor because the raw septic tank effluent was applied directly to the open access filter. With recirculating sand filters, the septic tank effluent was always mixed with return flow from the filter, therefore, alleviating this problem to some degree. Louden et al. (1985) found that the evidence of odor could not be detected during operation. Through neighborhood surveys, Louden et al. (1985) reported that no neighbor ever indicated the presence of odor from the system.

During the severe winter months in Michigan, Loudon et al. (1985) found that the recirculating sand filter could be operated without failure, even though massive amounts of ice formed on both filters studied. The ice cones developed to a considerable height around the sprinkler, but remained hollow, thereby allowing the sprinkler to operate normally. One concern was that the ice would form a sheet in the upper sand layer, obstructing the vertical flow through the filter. Loudon et al. (1985) found that even though a small layer formed, it was melted and infiltrated into the sand during subsequent sprinkler applications.

For evaluating system performance, Loudon et al. (1985) considered the sand filter effluent as the system output.

The first system, located in Northern Michigan showed effluent quality with BOD_5 of 12 mg/l, fecal coliforms of 210 CFU's/100 ml, and total nitrogen of 31 mg/l. The East Lansing site performed slightly better with BOD_5, fecal coliforms and total nitrogen values of 6 mg/l, 14 CFU's/100ml and 26 mg/l, respectively.

Hathaway and Mitchell (1985) studied a sand filter system constructed at the University of Arkansas, which applied renovated wastewater to a residential lawn. The sand filter was built of 5 cm (2 inches) of rounded 3/4-inch gravel on top, followed by 25.4 cm (10 inches) of coarse filter sand, 5 cm (2 inches) of gravel, 10.2 cm (4 inches) of fine filter sand, 5 more cm (2 inches) of gravel, and finally 25.4 cm (10 inches) of glass sand. The sand filter was loaded at a rate of 61 liters per day per square meter (1.5 gallons per day per square foot) uniformly distributed over a twelve hour period. Three research plots were used to determine the impact of applying renovated wastewater. The first plot received the sand filter effluent, the second plot received city water at the same rate and the third plot was left unirrigated.

The sand filter effluent was tested for total organic carbon (TOC), fecal coliforms, total coliforms and phosphorus. The TOC concentrations in the effluent ranged from approximately 0 to 40 mg/l with an average of 10 mg/l. The sand filter effluent contained an average total coliform count of 4 CFU's/100 ml during periods of normal operating conditions. However, during a one-month period of loading the sand filter at a rate of 114 liters per day per square meter (2.8 gallons per day per square foot) the sand filter effluent showed results too numerous to count per 100 ml (Hathaway and Mitchell, 1985). The average fecal coliform count during normal operation was reported as 1 CFU/100 ml. Concentrations of ammonia and nitrate in filter effluent were not reported by Hathaway and Mitchell (1985).

Hathaway and Mitchell (1985) reported on the stormwater runoff quality from each of three plots studied during the project. The three plots were designated as "Irrigated" (with system effluent), "City Water", and "Without". The Irrigated and City Water plots had approximately 136 liters per day (36 gallons per day) of liquid applied to them, while the Without plot received no artificial application. Total organic carbon (TOC) averages were reported as 13 mg/l for the Irrigated plot, 14 mg/l for the City Water plot, and 19 mg/l for the Without plot. Average ammonia values were 2.0 mg/l, 1.4 mg/l, and 2.1 mg/l, respectively. Nitrate values were reported as 2.3 mg/l, 1.8 mg/l, and 2.4 mg/l for the Irrigated, City Water, and Without plots, respectively.

2.3 NITROGEN CHEMISTRY RELATED TO ON-SITE WASTEWATER RENOVATION

The most common contaminant identified in groundwater is dissolved nitrogen in the form of nitrate (NO_3^-)

(Eastburn and Ritter, 1984). Nitrogenous compounds in drinking water, from both surface and groundwater, have been a major concern to authorities for reasons of public health. Disposal of domestic sewage on or beneath the land surface is probably a contributing factor in the increasing spread of nitrogen contamination. Nitrogen's presence, in considerable concentrations, is threatening large aquifer systems (Eastburn and Ritter, 1984). Although, nitrate is the primary form in which nitrogen occurs in the groundwater environment, dissolved nitrogen also occurs in the form of ammonium (NH_4^+), ammonia (NH_3), nitrite (NO_2^-), nitrogen (N_2), nitrous oxide (N_2O) and organic nitrogen (Benefield and Randall, 1980).

Nitrates are of particular concern because, in sufficient concentrations in water, they can cause methemoglobinemia in infants and can also be toxic to livestock (EPA, 1975). Therefore, the United States Environmental Protection Agency (U.S.E.P.A.) and the World Health Organization (W.H.O.) set a water quality standard of 10 mg/l nitrate-nitrogen (45 mg/l NO_3^-) in the Primary Drinking Water Regulations (EPA, 1973). Walker et al. (1973) showed that nitrates in groundwater also contribute to the eutrophication of surface water due to the increased nutrient load applied to existing water vegetation.

Canter and Knox (1986) have published data which suggest that septic systems contribute to contamination of groundwater with nitrate. In one of their studies, shallow well water samples were collected from an area with a high density of septic systems. The results showed that over half the samples contained nitrate nitrogen concentrations greater than 10 mg/l.

Soil types and ground water levels can directly affect the probability of contamination by septic systems. In areas with high groundwater levels, a saturated soil provides anaerobic conditions. When this condition is present, nitrification may not occur. If nitrification does not occur, nitrogen in the septic tank effluent will remain primarily in the form of ammonium. Ammonium (NH_4^+) is attracted to negatively charged clay particles and is thus not very mobile in the soil. Ammonium may be converted to nitrate by oxidation in aerobic soils. Once this change occurs, there is an increased possibility of groundwater contamination, since the anionic form of nitrate causes it to be very mobile in soil environments (Brown et al., 1984).

In the process of domestic wastewater treatment, the most effective means of nitrogen removal is through biological nitrification and denitrification. In general, ammonium is converted to nitrate (through nitrification) and the nitrate is then converted to nitrogen gas (through denitrification) which is released into the atmosphere. An understanding of the processes involved is essential since the nitrification and denitrification processes involve different forms of bacteria and environmental conditions.

2.3.1 Nitrification

Most nitrifiers (nitrification organisms) are autotrophic organisms which utilize carbon dioxide or bicarbonates as a source of carbon (Gaudy and Gaudy, 1980). Nitrification is typically a two step process, such as:

$$NH_4^+ + 1.5O_2 + 2HCO_3 \text{ -----> } NO_2^- + 2H_2CO_3 + H_2O \qquad (1)$$

$$NO_2^- + 0.5O_2 \text{ -----> } NO_3^- \qquad (2)$$

The two major organisms involved, Nitrosomonas and Nitrobacter, carry out a symbiotic relationship (Benefield and Randall, 1980). The oxidation of ammonia to nitrite (Equation 1) produces energy for Nitrosomonas, while the further oxidation of nitrite to nitrate (Equation 2) yields energy utilized by Nitrobacter.

By combining Equations 1 and 2, the overall reduction of ammonium can be presented as (EPA, 1975):

$$NH_4^+ + 2O_2 + 2HCO_3 \text{ -----> } NO_3^- + 2H_2CO_3 + H_2O \qquad (3)$$

Sandy (1987) and Ford (1980) presented a slightly different form of the two step autotrophic process. As they described the process, ammonium is first oxidized to nitrite by *Nitrosomonas*,

$$NH_4^+ + 1.5O_2 \text{ -----> } NO_2^- + H_2O + 2H^+ \quad (4)$$

and the nitrite is then oxidized to nitrate by *Nitrobacter*

$$NO_2^- + 0.5O_2 \text{ -----> } NO_3^- \quad (5)$$

The combined reaction of ammonium to nitrate may be written as

$$NH_4^+ + 2O_2 \text{ -----> } NO_3^- + H_2O + 2H^+ \quad (6)$$

with the rate-limiting step of this reaction being the conversion of ammonium to nitrite.

There are many factors which directly affect the process of nitrification. Both *Nitrobacter* and *Nitrosomonas* are autotrophic aerobes with a relatively slow generation period (Canter and Knox, 1986), thus implying that time is a significant factor.

Temperature is another of the important factors which influence nitrification. The optimum temperature for nitrification has been reported to generally be in the range of 28 to 32°C (Brown et al., 1984). Ford (1980) has noted that nitrification tends to cease below 5°C or above 45°C. Ford (1980) also cited that there was a significant reduction in nitrification rate as the temperature was reduced within this range. Therefore, the required detention time for nitrification may be several times greater in the colder winter months than in the warmer summer months.

The optimum dissolved oxygen level for maximum rate of nitrification has been subjected to considerable debate. Downing (1966) suggested that maximum rates of nitrification proceeded only at dissolved oxygen levels which were greater than 3 mg/l. However, the U.S. EPA (1975) reported no noticeable inhibition of nitrification at dissolved oxygen levels exceeding 1.5 mg/l, but, that dissolved oxygen levels below 0.5 mg/l had a detrimental influence on nitrification. This influence was expected at the lower dissolved oxygen levels when the nitrifying microorganisms are aerobic.

As shown in Equation 4, alkalinity is destroyed by the oxidation of ammonia as a result of the released hydrogen ions. Therefore, the autotrophic reactions require an inorganic source of alkalinity. Ford (1980) reported that approximately 7.1 mg of alkalinity as $CaCO_3$ was destroyed per mg NH_3-N (ammonia-nitrogen) oxidized while Randall and Buth (1984) reported that 7.14 mg of $CaCO_3$ and 4.57 mg of O_2 was destroyed per mg NH_3-N oxidized.

Nitrifying bacteria are very sensitive organisms and have extremely low tolerance for inhibitory substances. These can include toxic organic compounds along with heavy metals, however, two of the most important inhibitory compounds are substrate induced (Ford, 1980). Anthonisen (1976) and Ford (1980) identified the boundary levels of free ammonia (FA) and free nitrous acid (FNA) as inhibiting species for nitrification.

Ford (1980) reported results from a series of experiments to identify these boundaries. The concentration limits are:

1) FA inhibited <u>Nitrosomonas</u> at a concentration of 10 to 150 mg/l and inhibited <u>Nitrobacter</u> at a concentration of 0.1 to 1.0 mg/l; and

2) The inhibition of nitrifying organisms occurred at FNA concentrations between 0.2 and 2.8 mg/l.

Both the FA and FNA concentrations are a function of the pH and the ionized form and concentration of the substrate (Ford, 1980). Although the rate of nitrification is assumed constant in the pH range of 7.2 to 8.0, Ford (1980) showed results which indicated a pH range optimum for nitrification as 7.5 to 8.5.

2.3.2 Denitrification

Denitrification is the second step in the biochemical pathway of the nitrogen removal cycle. The process of denitrification is accomplished by a broad range of heterotrophic bacteria. These bacteria operate under anoxic or anaerobic conditions which force them to use nitrate and nitrite as the terminal electron acceptors (Eastburn and

Ritter, 1984). Organic compounds (as found in raw septic tank effluent) are the source of energy and carbon required to drive the denitrification process.

Denitrifying bacteria are facultative, which means that a sufficient concentration of dissolved oxygen can prevent the use of nitrate and nitrite nitrogen as the terminal electron acceptor. Rittman and Langfield (1985) showed that when denitrifying bacteria are exposed to 0.1 to 0.2 mg/l of oxygen, they select the oxygen and do not denitrify.

Sandy (1987) presented the two-step process of denitrification in the following equations:

$$6NO_3^- + 2CH_3OH \text{ -----> } 6NO_2^- + 2CO_2 + 4H_2O \quad (7)$$

$$6NO_2^- + 3CH_3OH \text{ -----> } 3N_{2(g)} + 3CO_2 + 3H_2O + 6OH^- \quad (8)$$

The overall reaction for the conversion of nitrate to gaseous nitrogen is expressed as:

$$6NO_3^- + 5CH_3OH \text{ -----> } 3N_{2(g)} + 5CO_2 + 7H_2O + 6OH^- \quad (9)$$

A slightly different set of equations was presented by the EPA (1975). These were as follows:

$$NO_3^- + 0.33CH_3OH \text{ -----> } NO_2^- + 0.33H_2O + 0.33H_2CO_3 \quad (10)$$

$$NO_2^- + 0.5CH_3OH + 0.5H_2CO_3 \text{ -----> } 0.5N_{2(g)} + HCO_3^- + H_2O \quad (11)$$

The overall expression for the denitrification can be written as:

$$NO_3^- + 0.83CH_3OH + 0.17H_2CO_3 \text{ -----> } 0.5N_{2(g)} + 1.33H_2O + HCO_3^-. \quad (12)$$

Equations 7 through 12 indicate that an organic compound is required by denitrifying bacteria as a source of carbon and energy. This organic compound was shown as CH_3OH (methanol) in Equation 12. Piluk (1988) reported that 3 mg of methanol was required per mg of NO_3^--N for almost complete denitrification.

Two other factors which have been shown to affect denitrification rate are temperature and pH. EPA (1975) reported that the highest denitrification rates occurred within a pH range from 7.0 to 7.5. Eastburn and Ritter (1985) showed that denitrification rates increased with temperature over a 2 to 25^oC (35.6 to 77.0 ^oF) range. However it has been commonly reported that denitrification tends to cease at temperatures below 5^oC (41.0 ^oF).

2.4 ON-SITE FILTER SYSTEMS EMPHASIZING NITROGEN REMOVAL

The major thrust during recent years has been to develop recirculating sand filters which optimize biological processes for the removal of harmful chemical and organic constituents in the septic tank effluent. Numerous studies have been performed on recirculating sand filters in an effort to achieve an optimum design. Most researchers have found that the biological processes are inter-related, and that performance characteristics must generally be evaluated for multiple parameters of the effluent quality. Systems presented by Sandy et al. (1987), Swanson and Dix (1988), and Piluk (1988), were designed to enhance the removal of nitrogen.

Sandy et al. (1987) performed numerous studies to enhance nitrogen removal from a system termed a batch recirculating bottom ash filter (BRBAF). The BRBAF system differed from conventional recirculating filters in three distinct ways. First, the sand media was replaced by a power plant waste material known as bottom ash. Second, the rock storage filter was placed directly beneath the filter (bottom ash) media, rather than in a separate recirculation tank. The third difference was that the highly nitrified filter effluent was recycled back to the septic tank. It was believed that this recycling scheme would allow the system to take advantage of the organic carbon available in the septic tank. The amount of organic carbon has often been shown as a limiting factor in the denitrification process, and it was suggested by Sandy et al. (1987) that this arrangement would allow the system to use the otherwise "wasted" carbon source.

Sandy et al. (1987) ran a series of eight distinct tests to evaluate a batch recirculating bottom ash filter (BRBAF). The results of two of their runs are reported here. The first set of data is from run #4 where the entire BRBAF was used for nitrification/denitrification in the bottom ash filter and denitrification in the septic tank (Sandy et al., 1987). Run #4 lasted a total of 22 days (October 15, 1986 to November 5, 1986), during which time seven sets of samples were taken. The test had a septic effluent hydraulic loading rate (SHLR) of 978 liters per day per square meter (24 gallons per day per square foot) and a recirculation ratio of 17:1. The total nitrogen concentration of the bottom ash filter effluent (BAFE) was reported as an average of 9.63 mg/l and total Kjehldal nitrogen (TKN) was an average of 7.02 mg/l. The septic tank effluent (STE) concentrations for total nitrogen and TKN averaged 16.64 mg/l and 16.01 mg/l, respectively. Sandy et al. (1987) also reported BOD_5 and fecal coliform BAFE concentrations for run #4 as 8.5 mg/l and 100 CFU's/100ml, respectively. The data for these last two concentrations were taken on a monthly basis, while the nitrogen data were taken every three to five days.

Run #8 was performed from January 29, 1987 to February 13, 1988. This run had an SHLR of 652 liters per day per square meter (16 gallons per day per square foot) and a recirculation ratio of 10:1. Run #8 was used to determine if cold weather operation had any effect on the nitrogen removal efficiency of the BRBAF. Results for run #8 were reported as 13.2 mg/l and 1.5 mg/l BOD_5 for the STE and BAFE, respectively. Average (for six samples) total nitrogen and TKN concentrations wer reported as 8.97 mg/l and 3.13 mg/l, respectively for the BAFE. The STE had an average total nitrogen concentration of 10.55 mg/l while the average TKN concentration was 9.65 mg/l.

Swanson and Dix (1988) utilized a recirculating filter with rock storage/filter (RSF^2) which eliminated the need for a separate recirculation tank. The overall system consisted of a septic tank, the RSF^2 and an ultraviolet disinfection unit. A bottom ash media of effective size 2.4 mm (0.095 inch) to a depth of 80 cm (31.5 inches) was used in the filter. The septic effluent hydraulic loading rate varied from 11 to 20 cm/day (2.8 to 5 gallons per day per square foot) on the filter with a recirculation ratio of 5:1 to 9:1.

Despite a wide variation in operating conditions and parameters, the effluent quality was maintained throughout the monitoring program (Swanson and Dix, 1988). Over the 8 month, 39-sample monitoring program, the RSF^2 effluent averaged 8.4 mg/l BOD_5, 7.7 mg/l suspended solids, and 9.3 mg/l TKN (Swanson and Dix, 1988). Influent values averaged

148.6 mg/l BOD_5, 76.7 mg/l suspended solids and 57.4 mg/l TKN. Fecal coliform counts from the RSF^2 influent averaged 3.3×10^5 CFU's/100 ml, the effluent averaged 2.3×10^4 CFU's/100 ml, while the ultraviolet disinfection unit reduced the fecal coliform population to zero for six of the eight samples taken (Swanson and Dix, 1988).

Piluk (1988) reported on a recirculating sand filter system located in Anne Arundel County, Maryland, which was designed primarily for nitrogen reduction. The on-site treatment system consisted of a septic tank, a nitrogen reducing tank, a pump pit, a polishing sand filter and a trench that penetrated a seasonal water table (Piluk, 1988). Wastewater flows were channelled through the septic tank and into the nitrification/denitrification (N/D) tank. The N/D tank was constructed in three sections with the bottom section functioning as a submerged gravel filter for denitrification, the middle as a sand filter for nitrification, and the top as an air space. After filtering through the gravel filter in the N/D tank, the liquid flowed into a pump pit where approximately 77% was recirculated to the N/D tank and sprayed onto the surface of the sand layer in the N/D tank (Piluk, 1988). The other 23% of the flow was sprayed onto a polishing sand filter constructed over a 260 cm (102 inches) deep trench that penetrated a seasonal water table (Piluk, 1988).

The N/D tank was constructed of 2 cm (0.79 inches) washed gravel placed to a depth of 95 cm (37.4 inches) followed by 5 cm (1.9 inches) of pea gravel with 63 cm (24.8 inches) of sand placed on top. The sand had an effective size of 1 mm (0.039 inch) and a uniformity coefficient of 2.2. During operation, an outlet pipe allowed 70 cm (27.56 inches) of water to remain in the N/D tank at all times (Piluk, 1988).

The system effluent (taken as the output from the sand filter) data was presented by Piluk (1988) as an average total nitrogen concentration of 17.7 mg/l, a TKN concentration of 1.9 mg/l and COD of 21 mg/l. The fecal coliform (MPN) was also reported as 3.3×10^2 CFU's/100 ml. Average influent concentrations were reported as 69.4 mg/l total nitrogen, 69.2 mg/l TKN, 514 mg/l COD, and fecal coliforms of 1.0×10^7 CFU's/100 ml.

2.5 DISCHARGE OF RENOVATED DOMESTIC WASTEWATER

The on-site wastewater treatment system is not complete until the treated effluent has been properly discharged. Soil and site conditions render many areas unsuitable for the use of conventional soil absorption systems for on-site wastewater renovation (Effert et al., 1985). On-Site treatment systems may discharge effluent into one of several receptacles. These include: streams and ditches, sewage treatment plants, or land via sprinkler application.

Rivers and streams have historically been a readily available means of waste disposal (Arceivala, 1981). Streams have been so utilized more than lakes and estuaries due to their flowing condition. However, the ecosystem as well as the beneficial uses of the stream must be considered. The renovated wastewater can exert substantial oxygen demand, and the increase of nutrients such as nitrogen and phosphorus can produce heavy algal growths in downstream sections (Arceivala, 1981).

Some types of on-site treatment systems have been designed to discharge renovated wastewater into collection systems leading to wastewater treatment plants. In New York, some sand filter cluster systems in out-lying areas are used to pretreat wastewater before it is transported by sewer to a central plant for final treatment (Perley, 1985). Otis (1985) cited the use of effluent drains as an economical alternative to traditional sewer systems for areas with low population densities. Due to the utilization of on-site pretreatment, effluent drains can be designed with minimal pipe diameters and minimum flow velocities (Otis, 1985). From an economic viewpoint, the effluent drain can be considerably cheaper than sewer collection systems when used with on-site treatment systems.

Sprinkler irrigation of sand filter effluent has been studied by numerous authors such as Hathaway and Mitchell (1985), Scherer (1982) and Rubin (1988). Hathaway and

Mitchell (1985) found that land application of sand filter effluent had no appreciable effect on the quality of the runoff water from the site of application. In some instances land disposal has become a successful method to achieve primary, secondary and tertiary treatment in a single operation (Arceivala, 1981).

During land application of renovated wastewater, the soil becomes an additional filter to further improve the quality. Unlike below-grade disposal systems, land application allows use of the entire soil profile; including the aerated, biologically active upper zone. This is particularly important in areas with shallow soils and high water tables. Waggy and Griffes (1986) cited results of renovated wastewater applications systems over a twelve-year period showing that land treatment can be very competitive relative to conventional methods of wastewater treatment.

The most prominent public concern with land application of renovated wastewater has been the perceived potential health risks. The issue of health risk from applying domestic waste on residential land must, therefore, be addressed before such practices will gain acceptance.

Studies cited by Guentzel (1977) and Johnson et al. (1977) showed that land application of wastewater can present a risk of infection through aerosols. However, most of the cases which were documented showed that the wastewater being applied had high concentrations of viral and pathogenic organisms (Johnson et al., 1977). Dorcey and Howe (1977) stated that, although land application can threaten public health, proper wastewater renovation and careful management will alleviate the risk of contamination. Results from some previous studies suggest that sand filters may fit into a system for managing septic tank effluent so that it may be safely irrigated onto lawns(Scherer, 1982 and Rubin, 1988).

2.6 HEALTH RISKS FROM PATHOGENS IN WASTEWATER

Centuries ago, Romans recognized that crop growth was improved when manure was added to the soil. During the period of history when fertilizer and energy were inexpensive, it was more convenient to regard municipal and animal wastes as disposal problems rather than resources. Recently, in most crop-producing sectors, wastes have been considered valuable resources. Unfortunately, concern exists as to whether the application of municipal wastes to cropland can present pathogenic hazards.

The utilization of animal wastes for crop production has been an accepted practice, and people are not normally disturbed by animals feeding and defacating in the same area (Menzies, 1977). However, the potential concentration of human pathogens when municipal wastewaters are used to irrigate land causes many people to have strong reservations concerning its use. Several benefits, however, counter the negative concern about land application. For example (Menzies, 1977):

* Depleted nutrients can be replaced in the soil.

* Physical structure can be improved in most soils.

* Wastewater can be purified by passing through the soil and ultimately recharging the groundwater supply.

* Pollution of streams, rivers, lakes and oceans with sewage wastes can be avoided.

More than 1,000 communities in the United States have recognized the benefits, and as of 1973, were utilizing land application as a means of renovating sewage wastes (Sullivan et al., 1973).

Although these benefits have great significance, the concern about toxicity to plants, animals, and humans as a result of potential pathogens present in the wastewater and sludge still exists.

The principle pathogens found in sewage can be divided into four groups (Berg, 1983):

* Bacteria
* Protozoa
* Helminths (intestinal worms), and
* Viruses

Some of the prominent pathogens and the diseases they cause are represented in Table 2.1 (Berg, 1983).

Processed wastewater may contain all of the four groups of pathogens shown in Table 2.1; or they may contain none or

Table 2.1 Major Pathogens Found in Sewage and Diseases Associated With These Pathogens.[a]

Organism	Disease
Bacteria	
Salmonella spp.	Salmonellosis
Shigella spp.	Shigellosis
Mycobacterium tuberculosis	Pulmonary tuberculosis
Protozoa	
Entamoeba histolytica	Amoebic dysentary
Helminthic parasites	
Ancylostoma duodenale	Hookworm infection
Necator americanus	Hookworm infection
Trichuris trichuira	Trichuriasis
Viruses	
Poliovirus	Poliomyelitis
Coxsackievirus	Aseptic meningitis Gastroenteritis
Adenovirus	Acute respiratory infect. Infant pneumonia
Hepatitis virus	Infectious hepatitis

[a] Source: Berg (1983)

only part of the pathogens. Berg (1977) stated that neither secondary treatment nor chlorination removed all viruses from effluent. Podusha and Hershey (1972) reported that although viruses survive in wastewater, they are also able to survive in natural and other water supplies which allow transmission to humans.

Salmonella bacteria are readily detectable in sewage wastes. However, of the more than two million cases of Salmonellosis reported annually in the United States, it has rarely been associated with sewage waste (National Research Council Committee on Salmonella (NRCCS), 1969). The NRCCS (1969) reported on two instances of Salmonellosis contamination. The first occurred when activated sludge was spread on a hospital lawn and an outbreak of Salmonellosis was recorded among those in contact with the area. In the second instance, several children were infected with Salmonellosis from sewage sludge spread on their home lawn. In both cases, the nature and extent of treatment of the sludge was unknown.

It would appear that survival of viruses in wastewater going through treatment processes, and the subsequent introduction of viruses into surface and groundwater, would constitute an important source of enteric viral diseases. According to Grabow (1968), the number of cases of enteric viral diseases is surprisingly small in relation to the estimated quantities of viruses in most wastewaters. Clark et al. (1971) reported that, of the enteric viral diseases, only infectious hepatitis shows evidence of being truly waterborne. Berg (1977) stated that the predominant method of transmission of enteric viruses appeared to be a direct fecal-to-oral route. Mosley (1965) found that transmission through water did not cause a significant portion of gastroenteritis and diarrheal disease outbreaks.

Although the fecal-to-oral route appears to be the dominant mode of transmission for infectious hepatitis, waterborne and foodborne outbreaks do occur. Craun (1974) reported that waterborne infectious hepatitis outbreaks in the United States have been limited almost exclusively to small private water supplies contaminated by septic tank systems. However, when Glass and Jenkins (1962) surveyed 401 sewage treatment plants in the United States which utilized sprinkler disposal of treated sewage waste effluent they found no evidence that the health of nearby residents or the treatment plant workers was adversely affected (Glass and Jenkins, 1962).

The presence of infectious agents in water and wastewater has historically been estimated using the coliform test. Because of the variety of microorganisms that may be present, it has been infeasible to determine the presence of each agent. Therefore, the coliform bacteria group was chosen as an indicator of fecal contamination. If the coliform test indicates the presence of coliform bacteria, there is a possibility that other pathogenic microorganisms of fecal origin might also be present.

Information available on human dose response for typhoid fever, some forms of salmonella, and strains of E. Coli and Giardia lamblia was presented by the EPA (1979). Bryan (1974) compiled the dose response shown in Table 2.2 for a variety of infectious agents. Although the dose response varies from one organism to another, it normally takes a considerable number of organisms to elicit a significant response in those subjects infected. Data for enteric virus dose response are not well documented. A number of researchers believe that an infective dose can be initiated with one enteric virus particle, however, others contend that an effective dose requires a much greater number of virus particles. Lennette (1976), in defense of this states:

> "The contention that a single viral particle invariably or even frequently constitutes a minimal infective dose for man is simplistic and misleading. It fails to take into account the considerable amount of data from oral polio vaccine studies which are nonsupportive of this contention and ignores the manifold factors associated with the humoral and allular immune responses of the animal as well as the chance factors--which under natural conditions surely must be enormous--that a single viral particle contained in a particle of food or drink will find its way through the mechanical barriers of saliva, mucus, gastric acid, etc.; encounter a susceptible cell; find the appropriate receptor site on that cell; and enter and replicate sufficiently to spread to other cells.

Table 2.2 Dose Response for Selected Enteric Microorganisms.[a]

Microorganisms	No. per Dose[b]
Shigella sp.	$10^2 - 10^3$
S. Typhi	$10^4 - 10^7$
Salmonella sp.	$10^6 - 10^9$
E. Coli	$10^5 - 10^{10}$
Vibrio Cholerae	$10^3 - 10^8$
Giardia Lamblia	$10^1 - 10^6$ [c]

[a] Source: Bryan (1974)
[b] Needed to produce illness in 25 to 75% of persons taking dose
[c] infection without illness

Since the coliform bacteria test is used as an indicator of enteric bacterial pathogens; a relationship between the two is of considerable importance in water and wastewater studies. Kehr and Butterfield (1943) indirectly related the number of S. Typhi per million coliforms to the morbidity of typhoid in the community as:

$$y = ar^n \qquad (13)$$

where y = number of S. Typhi per million coliforms
a = a constant
r = the morbidity of the disease per 100,000
n = a constant.

The constants for Equation 13 were reported by Kehr and Butterfield (1943) as a = 3 and n = 0.46. From data reported for the United States (EPA, 1979), the morbidity of typhoid fever is 0.18 per 100,000. Therefore, a value of 1.4 typhoid bacilli per million coliforms would be estimated. The EPA (1979) assumed that the same relationship would apply to salmonella and shigella, and reported an estimate of 36 salmonella and 29 shigella organisms per million coliforms. It must be noted that these numbers were based on the disease rate for the entire country. A local epidemic would result in higher numbers of pathogens per million coliforms, and the equation may greatly underestimate the number. The relationship by Kehr and Butterfield (1943) showed that the risk of contracting these diseases from water is slight.

A sophisticated statistical analysis was performed by Dudley et al. (1976) to determine the risk to swimmers of contracting typhoid or salmonella from bathing water. They used the dose response from Bryan (1974) (Table 2.2) and assumed that a swimmer would ingest 10 ml of water. Using the morbidity rate of 0.18 per 100,000 and assuming that untreated wastewater contained 10^9 coliforms per 100 ml, they found that 1,300 typhoid bacilli organisms should be present in 100 ml of untreated wastewater. They stated that if this number of typhoid bacilli were present in untreated wastewater and were ingested by a population of swimmers, the rate of disease would be less than 20 cases per 100,000 population. In the case of salmonella, the same activity would be expected to produce less than four cases in 100,000 people. These predictions must be used in context, since they are based on the assumption that people directly consume untreated wastewater.

2.7 WATER STANDARDS AND QUALITY OF EXISTING SYSTEMS

The water quality standards for recirculating sand filter systems have generally been set by the type of disposal method used. The effluent of systems which discharge directly into potable or drinking water sources have been placed under stringent quality standards, while other systems which utilize irrigation or land application as an added treatment have fallen under less strict categories. The U.S. EPA (1979) reported data for the estimated concentration of infectious agents throughout a wastewater treatment system utilizing land application. Table 2.3 shows a portion of the data presented (EPA, 1979).

Nemerow (1985)investigated the overall concept of pollution in relation to numerous forms of water usage. He documented water quality standards which were established on the basis of the most beneficial use rather than one set standard for all water. The National Technical Advisory Committee on Water Quality Criteria of the Federal Water Pollution Control Administration considered the following uses to be important enough to establish criteria (Interim Report, 1967):

1. Aesthetics and recreation
2. Public water supplies
3. Fish, other aquatic life and wildlife
4. Agriculture, and
5. Industrial water supplies.

The National Committee defined the criteria for aesthetic purposes such that "all surface waters should contribute to the support of life forms of aesthetic value." (Interim Report, 1967). No actual numbers were recommended by the Committee. Instead, they suggested the general criterion be implemented by the recommendation that surface waters should be free of substances attributable to discharges of waste as follows (Interim Report, 1967):

Table 2.3. Infectious Agents in Wastewater at Various Points in a Typical Waste Treatment Process for Land Application.[a]

Process	Coliforms #/100 ml	Salmonella #/100 ml	Shigella #/100 ml	Virus #/100 ml
Wastewater collection	$3x10^7$	$4x10^3$	$4x10^3$	$1.9x10^3$
Headworks	$3x10^7$	$4x10^3$	$4x10^3$	$1.9x10^3$
Aerated lagoon	$3x10^5$	20	20	1.9
Storage lagoon	$3x10^3$	0.2	0.2	$1.9x10^{-2}$
Field distrib.	$3x10^3$	0.2	0.2	$1.9x10^{-2}$
Soil surface	30-360	$1.3x10^{-2}$	N.D.[b]	$2.1x10^{-3}$

[a] Source: EPA (1979)
[b] N.D. Not detected

A. materials that will settle or form objectionable deposits,

B. floating debris, oil, scum and other matter,

C. substances producing objectionable color, odor, taste and turbidity,

D. materials including radionuclides in concentrations or combinations which are toxic or which produce undesirable physiological responses in human, fish, and other animal life and plants, and

E. substances and conditions or combinations thereof in concentrations which produce undesirable aquatic life.

The reasoning for the suggested guidelines rather than strict numerical regulations was to allow specific criteria to be established for local situations.

The National Committee (Interim Report, 1967) recommended the following criteria for waters of primary contact sports: "Fecal coliforms should be used as the indicator organism for evaluating the microbiological suitability of recreational waters." As determined by multiple tube fermentation or membrane filter procedures, and based upon a minimum of not less than five samples taken over not more than a 30 day period; the fecal coliform content shall not exceed a geometric mean of 200 colony forming units (CFU) per 100 ml, nor shall more than 10 percent of total samples during any 30 day period exceed a value of 400 CFU's/100 ml.

In their Interim Report (1967), the committee described permissible use to include those characteristics and concentrations of substances in raw surface waters which will allow the production of a safe, clear, potable, aesthetically pleasing and acceptable public water supply. The permissible criteria for total and fecal coliform concentrations were set at 10,000 and 2,000 CFU's/ 100 ml, respectively. For nitrogen as nitrates plus nitrites, the permissible level was set by the U.S. EPA (1973) for primary drinking water at 10 mg/l.

Irrigation water has been considered in terms of agricultural use rather than domestic or residential use. Biological characteristics of irrigation water which was deemed to have little or no detrimental effects on crop growth included monthly total and fecal coliform averages of 5,000 and 1,000 CFU's per 10 ml, respectively (Nemerow, 1985).

Municipal effluents and stream water characteristics were compared to the maximum contaminant levels (MCL) for wastewater reuse by Nemerow (1985). Table 2.4 shows the criteria of selected parameters as outlined by Nemerow (1985) and the E.P.A. (1978).

Nemerow (1985) also cited acceptable water quality for reuse of effluents for power plant and industrial cooling

Table 2.4 Comparison of Secondary Effluent Quality to Stream Water Quality and Drinking Standards.[a]

Parameter	Drinking Water MCL	Stream Low	Stream Typical	Stream High	Municipal Secondary Effluent Typical
Nitrate-N (mg/l)	10	<1	1	3.4	1
Coliform (CFU/100ml)	1	<100	1,000	$1.5x10^7$	$1x10^7$
COD (mg/l)	0	2.5	30	125	100

[a] Source: Nemerow (1985) and EPA (1978)

waters. Values for BOD, coliforms, organic nitrogen and nitrate for a number of these plants are shown in Table 2.5 (Nemerow, 1985).

Numerous on-site domestic wastewater irrigation systems have been installed in the state of North Carolina since 1978 (Rubin, 1988). These systems are designed exclusively for domestic wastewater renovated with sand filters. North Carolina state regulations require sand filtration with some form of disinfection (North Carolina Department of Human Resources, 1982). The wastewater renovation systems are designed to utilize the septic tank for primary settling, a sand filter for secondary treatment, a disinfection unit consisting of either chlorine or ultra-violet light and a pump tank with a minimum of five-day storage capacity (Rubin, 1988).

State regulations require 0.46 to 0.61 m (1.5 to 2 ft) of soil depth to groundwater over the application zone with no concave slopes or natural drainageways within the irrigation boundary. The irrigation area must be a minimum of 46 m (150 ft) from the property line, 61 m (200 ft) from the home served by the system, and 122 m (400 ft) from the nearest existing inhabited residence (Rubin, 1988).

The application rate for these systems ranges from 2.51 to 3.77 cm per week (0.4 to 0.6 in/wk) based on a water balance for the particular residence (Rubin, 1988a). Rubin (1988a) stated that the hydraulic load limits the

Table 2.5 Municipal Wastewater Effluent Quality for Power Plant and Industrial Cooling.[a]

Plant	BOD mg/l	Coliforms MPN CFU/100ml	Organic Nitrogen mg/l	Nitrate mg/l
Nevada Power Co. Las Vegas, Nevada	21	10	1.0	1.0-3.4
City of Denton Denton, Texas	10	16,000	N.R.[b]	N.R.[b]
City of Burbank Burbank, Calif.	2	2-62	39	8
El Paso Products Odessa, Texas	8	600,000	N.R.[b]	0.6
DOW Chemical Midland, Mich.	20-30	1,000	N.R.[b]	N.R.[b]

[a] Source: Nemerow (1985)
[b] Not reported

application rate since nutrient concentrations tend to be low in the renovated wastewater.

Slow rate spray irrigation systems have successfully been implemented to overcome soil and site limitations which preclude the use of conventional subsurface disposal (Rubin, 1988). With the extensive buffer zones and the slow application volume set by North Carolina standards, these systems require 743 to 930 m^2 (8,000 to 10,000 ft^2) of irrigation area for single family dwellings, and some sites may be precluded due to the large buffer zones required because of topographic constraints. Sand filter system technology has improved dramatically over the past decade--with new systems producing high quality effluent. However, few systems have been investigated with respect to the environmental impact of effluent applied to residential lawns. North Carolina appears to be the only state to impose state-wide limitations and regulations concerning the use of sprinkler application for on-site sand filter effluent. Research in this area should prove beneficial not only to regulatory agencies, but also to the public by freeing those areas with soil and site limitations for residential development.

2.8 SUMMARY

Insufficient soil depths and unsatisfactory hydraulic conductivity have negated, for many sites, the use of on-site wastewater renovation systems which utilize soil as a treatment media. Innovative and alternative designs such as low pressure pipe, at-grade, mound and soil drain systems have been developed to overcome many soil limitations. However, each of these alternatives continues to rely upon soil at the site for wastewater renovation. Recirculating sand filters appear to have significant potential for use as a non-soil based renovation component for on-site systems. In contrast to most other types of systems, recirculating filters may, with proper design and management, achieve significant removal of nitrogen in addition to the waste components normally removed by on-site renovation systems.

Application of effluent from recirculating filter systems onto lawn surfaces for final disposal has many attractive advantages. However, sufficient information has not been obtained to satisfy all concerns about health risks from such a practice.

3.0 OBJECTIVES

The overall purpose of this study was to evaluate a partially saturated recirculating sand filter as an alternative treatment for renovating domestic wastewater. The primary objectives of this study were to:

1. evaluate the ability of a partially saturated recirculating sand filter relying upon septic tank effluent as its only source of energy to remove nitrogen, COD, and coliform bacteria from domestic wastewater, and

2. assess the environmental impact of distributing septic tank effluent that has been renovated by a recirculating sand filter treatment system onto a lawn surface.

4.0 EXPERIMENTAL METHODS AND MATERIALS

A prototype recirculating sand filter (RSF) utilizing spray irrigation onto a lawn for discharge of renovated septic tank effluent was installed at the University of Tennessee Plant and Soil Science Field Laboratory near Knoxville, Tennessee. The system utilized a combination aerobic/anaerobic recirculating filter to remove waste components from septic tank effluent. Renovated wastewater was applied to a grassed plot once a day using a typical lawn watering sprinkler. Two other plots were installed with one being irrigated using potable water and the other left unirrigated (Figure 4.1). During the nine month operating period, (February, 1988 to November, 1988) water samples were collected from various points throughout the system and analyzed for COD; total Kjeldahl nitrogen; nitrogen in the forms of ammonia, nitrate and/or nitrite; fecal coliform bacteria; and total coliform bacteria. Vegetation samples were removed from within each plot to compare growth throughout the growing season. Runoff samples were collected during hydrologic events which produced runoff from the plots and analyzed for the same constituents as those listed above for water samples. Surface samples were collected from each plot quarterly to observe the coliform bacteria die-off rates after water application and to assess the potential for contact exposure to pathogens.

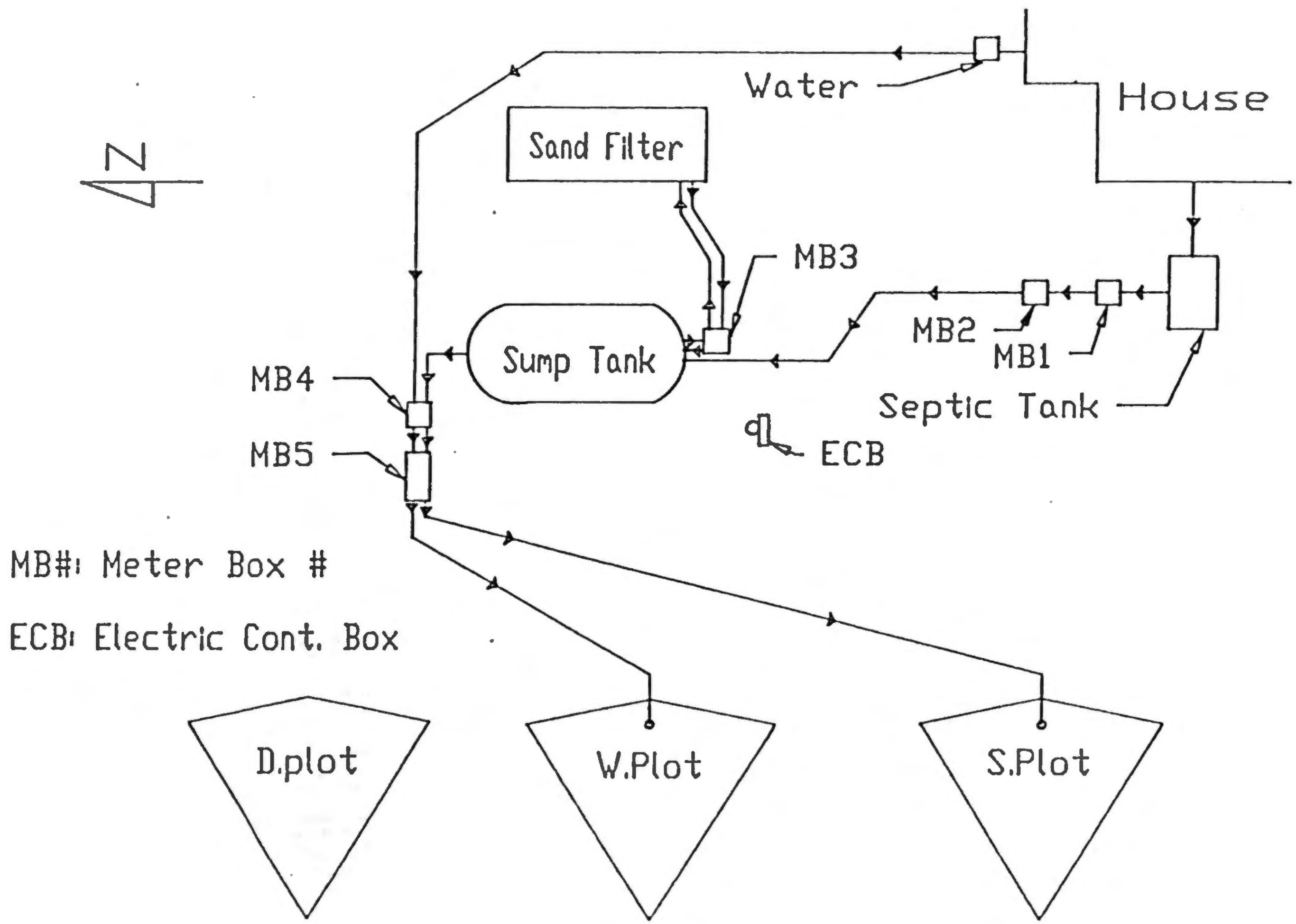

Figure 4.1 Recirculating Sand Filter Prototype System Layout.

4.1 PROTOTYPE RECIRCULATING SAND FILTER SYSTEM COMPONENTS

The RSF system consisted of an existing septic tank, a sump tank, a recirculating sand filter and a grassed plot to receive the renovated wastewater. Septic tank effluent was transferred from the septic tank to the sump tank on an hourly basis. Water from the sump tank was then applied to the top surface of the sand filter and allowed to drain, via gravity, back into the sump tank after passing through the filter media. Once each day an irrigation pump transferred water from the sump tank to a lawn sprinkler where it was applied to the lawn surface.

4.1.1 Septic Tank and Transfer System

The existing septic system was a 2840 liter (750 gallon) pre-cast concrete tank, with a subsurface absorption field. A PVC riser with lid was installed in the septic tank to provide access for a pump and sampling port.

The transfer system was designed to transfer approximately 364 liters (96 gallons) of septic tank effluent per day on an hourly basis. To achieve this, a 0.37 kilowatt ($^1/_{20}$ horsepower) submersible centrifugal pump was placed in the septic tank liquid zone. Suspended solids were filtered at the pump inlet by a PVC screen covered with a nylon mesh material originally intended for use as a mosquito net (mesh size unknown). On October 3, 1988 the inlet screen was replaced with a PVC vault covered with a single layer of mosquito netting. The submersible pump was then placed inside the vault, which afforded much more surface area and eliminated periodic flow reduction by clogging. The septic tank pump was connected to a $^3/_4$-inch nominal diameter PVC pipe buried approximately 46 to 60 cm (18 to 24 inches) below ground level. The pipe passed through two meter boxes (Figure 4.1). An in-line filter, containing a 40 mesh stainless steel screen, and a water flow meter were located in meter box 1 (MB1), while an anti-siphon valve and a gate valve were located in meter box 2 (MB2). The PVC pipe was run directly from MB2 into the sump tank and allowed to discharge near the bottom.

The septic tank pump was controlled by a 2-hour-per-cycle electro-mechanical timer and a time adjustable relay (variable from 1.8 to 180 seconds) located in the electrical control box (ECB). A float switch was also placed in the septic tank to keep the pump from operating if the water level dropped too low. The transfer volume was adjusted using the time adjustable relay and the gate valve installed in MB2.

4.1.2 Sump Tank

The sump tank was a 3785 liter (1000 gallon) single compartment plastic septic tank installed underground with two manhole risers extending 38 cm (15 inches) to ground level. The recirculation and irrigation pumps were located in the tank with inlet and outlet pipes connected through the end walls of the tank (Figure 4.2).

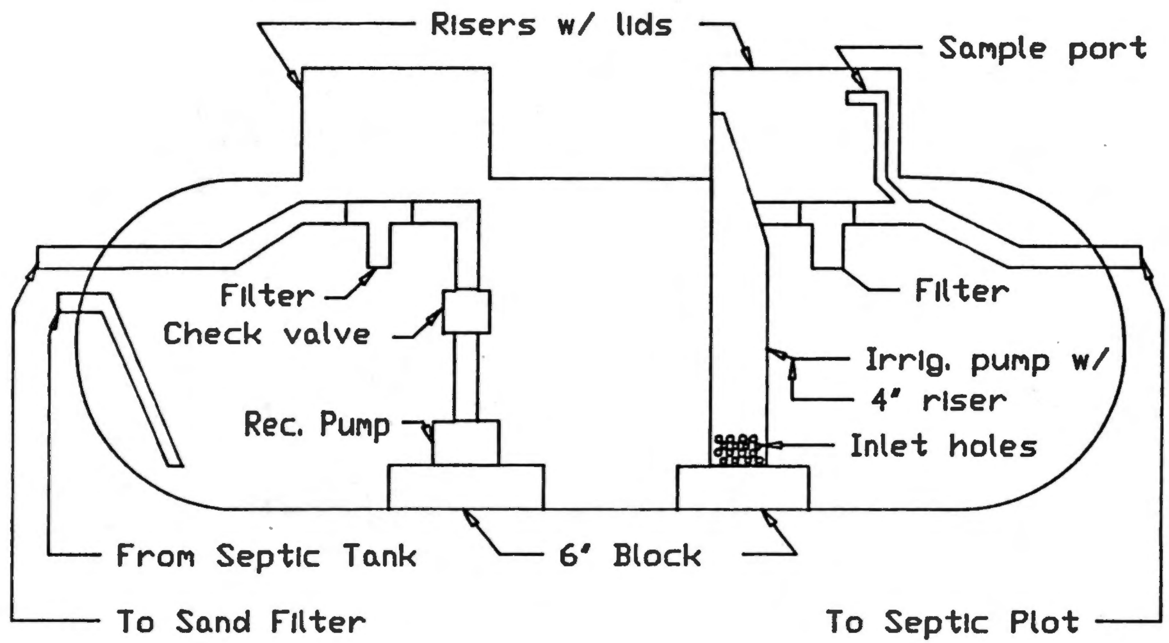

Figure 4.2 Sump Tank Configuration for Input and Output Flows.

4.1.3 Sand Filter

The sand filter was located upslope from the sump tank. The sand filter was sized based on 364 liters per day of raw septic tank effluent transferred into the system and the recommended loading rate of 122 liters of raw septic tank effluent per day per square meter (3 gallons per day per square foot) of sand filter area (Hines and Favreau, 1975). An effective area of 2.97 square meters (32 square feet) was required for the prototype design. The filter depth was selected to allow for 10 cm (4 inches) of charcoal, 30 cm (12 inches) of medium/coarse river sand and a 10-cm (4 inches) layer of gravel (Figure 4.3). The container selected for this prototype was a 2840 liter (750 gallon) oblong livestock watering tank made of galvanized steel. Dimensions of the tank were 3.6 meters (12 feet) long by 1.2 meters (4 feet) wide, with a depth of 0.61 meters (2 feet). The tank was fitted with two plywood baffles, which created an effective sand filter of dimensions 1.2 by 2.4 by 0.61 meters (4 by 8 by 2 feet).

The installation site was excavated to a depth of approximately 0.61 meters (2 feet), so that the filter tank would be contained primarily underground. The filter tank was covered with a three-section plywood lid attached to a wooden frame built around the filter. The wooden frame was constructed of 2x6 treated lumber attached to six 4x4 treated posts buried beside the tank. The lid was attached

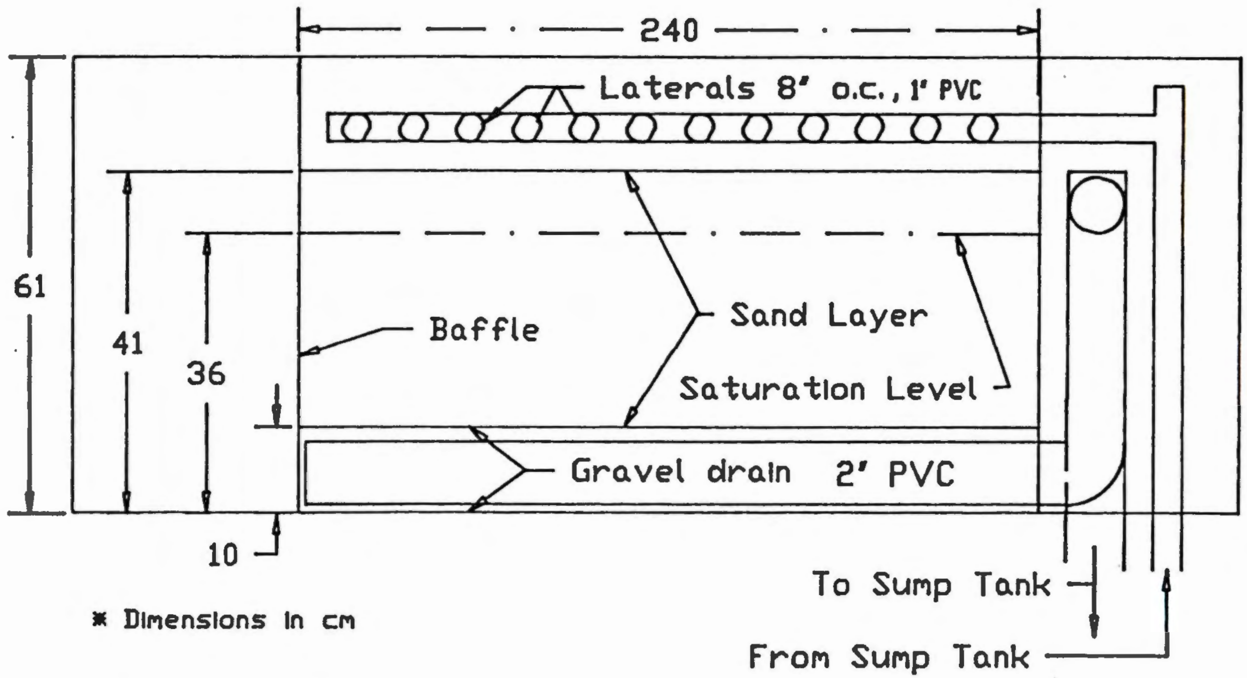

Figure 4.3 Sand Filter Cross Section to Show Saturation Zone Within Sand Layer.

on one side by hinges, and metal flashing was attached to both edges of the middle lid section to shed water away from the space between the sections.

The filter was constructed in layers by first placing a 2-inch nominal diameter PVC drain pipe, with a nylon mesh sock around it, along the bottom of the tank. The nylon sock (mesh size unknown) was originally intended for use as an envelope around a 4-inch nominal diameter soil drain line. A 10-cm (4 inch) layer of small gravel was placed in the bottom and a 1.2 by 2.4 meter (4 by 8 feet) piece of nylon mosquito netting was positioned on top of the gravel. Next, the medium/coarse river sand was placed over the gravel underdrain to a depth of 41 cm (16 inches) from the bottom of the tank, for a sand layer depth of 31 cm (12 inches). The sand layer was wetted with potable water and allowed to settle for one day before the level was rechecked. Finally, the charcoal layer was constructed of unactivated charcoal pellets which were washed and placed in 2.4 meter (8 feet) long nylon mesh socks. The tubes were then placed in the filter, side by side, in two layers.

The charcoal and the nylon mesh around the underdrain were removed on April 27, 1988. Unpublished results of laboratory studies performed in the Water Quality and Waste Management Lab at the University of Tennessee, Knoxville show no evidence that charcoal affects the renovation efficiency of the RSF system. The nylon mesh around the underdrain was removed due to clogging of the mesh by fine silt material washed out of the sand during operation.

4.1.4 Recirculation System

The recirculation system consisted of a submersible centrifugal pump (located in the sump tank) which delivered water to the sand filter through a manifold distribution line and the sand filter underdrain which returned the sand filter effluent to the sump tank. A recirculation ratio of 4 parts recirculated water to 1 part raw septic tank effluent (4:1) was selected based on recommendations for the RSF cited by Hines and Favreau (1975).

A 0.12 kilowatt ($^1/_6$ horsepower) submersible pump was placed on a 15 cm (6 inch) concrete block in the bottom of the sump tank. The pump was connected to a 1-inch nominal diameter PVC pipe used to transfer water from the sump tank to the distribution manifold. A ball check valve and an in-line filter (40 mesh stainless steel screen) were connected to the PVC pipe inside the sump tank. The PVC pipe was connected to a gate valve and a water flow meter located in meter box 3 (MB3) (Figure 4.1). The pipe was placed 46 to 76 cm (18 to 30 inches) below ground, from MB3 to the sand filter.

The distribution network was constructed of 1-inch nominal diameter PVC pipe with a single main having laterals attached to one side only. The lateral and orifice spacing was set at 20.3 cm (8 inches) on center, with an orifice diameter of 0.48 cm ($^3/_{16}$ inch). The manifold was connected to the pressure line from the sump tank with a PVC union to permit removal for cleaning as needed. The discharge rate from the distribution system at an operating head of 20.3 cm of water (8 inches) allowed an operation time of approximately 90 seconds every hour.

The 2-inch nominal diameter PVC underdrain below the sand filter was connected to a riser configuration which maintained a saturation zone approximately 36 cm (14 inches) deep in the filter media (Figure 4.3). Sand-filter effluent which had passed through the filter media was allowed to overflow through the riser and drain back to the sump tank.

The recirculation pump was controlled with a 4-hour-per-cycle electromechanical timer and a time adjustable relay (variable from 1.8 to 180 seconds) located in the ECB (Figure 4.1). With the 4:1 recirculation ratio, the pump was operated once every hour. However, during the period from June 14, 1988 to September 16, 1988 the recirculation ratio was increased to approximately 6:1 and the pump operated every forty minutes. This change was performed to check the response of nitrogen and carbon removal efficiencies at high recirculation rates.

4.1.5 Irrigation System

The irrigation system was designed to apply renovated wastewater to the system research plot via a lawn sprinkler. Lawn irrigation occurred at 4:00 a.m. daily and the volume was approximately equal to the septic tank effluent volume transferred into the system over a 24-hour period. A second sprinkler was installed to irrigate the water control plot with a volume of potable water equal to the volume of renovated wastewater applied to the research plot.

A 0.25 kilowatt ($^1/_3$ horsepower) deep well submersible pump designed to deliver a low flow rate at a high head was chosen to irrigate the renovated wastewater plot. The pump was physically placed inside a 4-inch nominal diameter PVC pipe mounted vertically in the sump tank (Figure 4.2). The pipe was used to direct water in through openings at the bottom and up around the motor for cooling. The pump/pipe configuration was placed on a 15 cm (6 inch) concrete block to raise the intake above any solids that might accumulate at the bottom of the sump tank.

The pump was connected by a $^3/_4$-inch nominal diameter PVC pipe to an in-line filter (40 mesh stainless steel screen) and a sample port in the sump tank. The pipe exited the tank approximately 60 cm (24 inches) below ground level and was connected to a solenoid valve and an anti-siphon valve in meter box 4 (MB4) (Figure 4.1). Meter box 5 (MB5), located immediately downstream of MB4, contained a gate valve, a 241.3 kPa (35 psi) pressure regulator and a water flow meter respectively. From MB5 the pipe was buried at a depth of approximately 60 cm (24 inches) and extended to the sprinkler head at the system research plot. The same arrangement of in-line components was connected to a potable water main used to irrigate the water control plot.

The sprinklers used on the research plots were TORO series 300-12-02 shrub hi-pop sprinklers, with a flow rate of 5.3 liters per minute (1.4 gallons per minute) and a spray radius of 6.7 meters (22 feet) at 207.8 kPa (30 psi). The sprinklers were installed 20 cm (8 inches) below ground level and extended 10 cm (4 inches) above ground level during operation. A PVC riser and lid arrangement was installed around the sprinklers to protect them from freezing temperatures when they were retracted.

Irrigation was controlled with a 24-hour electro-mechanical timer and a float switch. The irrigation system was turned on by the 24-hour electro-mechanical timer (at 4:00 a.m.) and off by the float switch when the volume in the sump tank had depleted to a set level. The circuit was also wired such that the irrigation system would not operate if an insufficient volume of septic tank effluent had been transferred into the system during the previous day.

There was also a high water level alarm float located in the sump tank. In the event that the accumulated water volume increased beyond one day's production, the float switch would turn on a bell alarm to alert the household. The alarm circuit was also designed to sound the bell if any of the pumps developed a short circuit, thus creating a potential hazard.

4.1.6 Research Plots

Three research plots were constructed to study the environmental impact of applying renovated wastewater to a lawn surface. The first plot received approximately 364 liters (96 gallons) of renovated effluent from the RSF system per day; while the second plot received approximately the same volume of potable water. The third plot was used as an overall control and received only water attributed to natural hydrologic events. These three plots were designated as System Research Plot (S.Plot), Water Control Plot (W.Plot) and Dry Control Plot (D.Plot) respectively.

Each of the three plots was isolated from outside runoff by earthen berms around the area of study. The berms were constructed in a triangular pattern to facilitate the installation of runoff flumes and stage recorders at the lower apex. The inside area of each plot was populated with a mixed culture of volunteer vegetation and was not disturbed, except in the area where the sprinkler heads were installed.

Flumes were installed at the lower end to measure and collect runoff. A collection basin was placed at the lower end of each flume to collect a composite water sample from each plot during runoff events. Both the flumes and collection basins were covered to ensure that the samples were indeed runoff and not precipitation.

4.2 SAMPLE COLLECTION

Samples were collected from various points throughout the system on a weekly basis. Water samples were taken of the septic tank effluent, sand filter influent, sand filter effluent, irrigation water before application, and the irrigated water from the S.Plot and W.Plot. Vegetation samples were taken from the grass as it was cut during the growing season for yield analysis. Runoff samples were collected from each of the plots during hydrologic events which produced runoff. Once each quarter, risk exposure samples were collected from each plot to assess the health risk potential related to contact of the lawn surface.

4.2.1 Septic Tank Effluent Samples

Septic tank effluent was collected from a sample port located inside the septic tank PVC riser. The sample port was connected to the line which transferred septic tank effluent into the system. Septic tank effluent was collected into sterile sample bottles by manually opening the sample port valve until the bottle was filled.

4.2.2 Sand Filter Samples

Sand filter samples were taken from the distribution manifold and the riser of the underdrain and designated as filter-in (F.I.) and filter-out (F.O.), respectively. A threaded plug was installed at the downstream end of the manifold for collection of the F.I. sample. The F.O. sample was collected with a sterile syringe from inside the riser just before the water overflowed back to the sump tank.

4.2.3 Preplot Samples

The preplot sample port was located inside the sump tank. A water sample bottle was placed at the port on the day prior to sampling to collect the water during the 4:00 a.m. irrigation event. The gate valve installed in the port was adjusted so that the sample bottle was filled during operation.

4.2.4 Research Plot Samples

System plot and wet control plot samples were collected during the irrigation event. Four sterile plastic beakers were placed on each research plot the day prior to sample collection, and left uncovered overnight. On the day of collection, the samples were transferred to sterile sample bottles for transporting to the laboratory. The beakers were also returned to the laboratory where they were washed, autoclaved and wrapped to reduce outside contamination.

Dry control plot samples were also collected on the sample day. Two sterile beakers were placed on the dry control plot the day prior to sample collection and left overnight. On sample day, 100 ml of sterile, distilled water was poured into each beaker and then transferred to sterile sample bottles and taken to the laboratory. If, during the period when the beakers were left out, a hydrologic event occurred, the volume was measured and noted during the laboratory analysis.

4.2.5 Vegetation Yield Samples

Grass on the research plots was cut, as needed, and the mass removed from a designated, representative area was measured. The remainder of the grass was cut and left on the plot. Grab samples of the grass were taken from each yield sample and analyzed for percent dry mass in the laboratory.

4.2.6 Runoff Samples

During hydrologic events producing runoff, composite samples were collected in beakers from the outflow of each flume. The runoff was transferred (as soon as possible after the end of the hydrologic event) to sterile water sample bottles and transported to the laboratory for analysis and a volume for each event was calculated from the stage recorder chart.

4.2.7 Risk Exposure Samples

Since the homeowner may directly contact the lawn surface, monitoring the coliform population was essential in determining the health risk associated with land application of renovated wastewater. Risk exposure assessments were performed on April 27, 1988; August 2, 1988; and November 9, 1988 for each of the plots. The procedure used was modified from one cited by Scherer and Mitchell (1982) and included a contact sample and a plant material sample. The contact sample was taken by a press-plate method, where a membrane filter and absorbent pad (soaked with the appropriate bacteria growth media) were pressed onto the lawn surface three times for an effective contact area of 52 cm^2 (8.1 square inches). Plant material samples were collected by cutting a portion of grass with sterile scissors and placing it into a whirl-pak bag for further laboratory analysis.

The risk exposure test lasted a minimum of 4 hours after irrigation. Samples were taken every 5 minutes for the first hour, every 15 minutes for the next 2 hours, and every 30 minutes for the remainder of the test period.

4.2.8 Climatological Data

Weather data was collected from the weather station located at the University of Tennessee Plant and Soil Science Field Laboratory. The data included air temperature and precipitation on a daily basis.

4.3 SAMPLE ANALYSIS

Water samples were analyzed for concentrations of organics, nitrogen, fecal and total coliform populations. Tests for organics and nitrogen were performed with the Technicon AutoAnalyzer II. Each test conformed to the standard methods for automated analysis (American Public Health Association, 1985). Fecal and total coliform determination was made using the standard membrane filter technique (American Public Health Association, 1985).

4.3.1 Organic Analysis

The chemical oxygen demand (COD) test was used as an indicator of the organic matter content in each sample. COD is a measure of the oxygen required to oxidize the organic matter in a sample. Concentrations of COD were determined by the closed reflux colorimetric method as described in Section 508C in Standard Methods for the Examination of Water and Wastewater (American Public Health Association, 1985). The lowest detectable level for the COD assay was 2.5 mg/l (i.e. a value of 0 mg/l is actually less than or equal to 2.5 mg/l).

4.3.2 Organic Nitrogen Analysis

The total Kjeldahl nitrogen (TKN) test measures the combination of organic and ammonia forms of nitrogen. Organic nitrogen content in each sample was quantified by determining TKN and subtracting the ammonia concentration found from an independent test. TKN determination was made by using the principles of the macro-Kjeldahl method and the apparatus of the automated Phenate method, as described in Sections 420A and 417G, respectively, of Standard Methods for the Examination of Water and Wastewater (American Public Health Association, 1985). Lowest detectable levels for TKN by this assay were 0.25 mg/l.

4.3.3 Ammonia Analysis

Determination of the ammonia form of nitrogen followed the guidelines of the automated Phenate methods, as described in Section 417G of Standard Methods for the Examination of Water and Wastewater (American Public Health Association, 1985). Lowest detectable levels for ammonia nitrogen (NH_3-N) by this assay were 0.05 mg/l.

4.3.4 Nitrite/Nitrate Analysis

The concentrations of nitrite/nitrate for each sample were found using an automated Cadmium reduction method, as described in Section 418F of Standard Methods for the Examination of Water and Wastewater (American Public Health Association, 1985). Lowest detectable levels for nitrate/nitrite nitrogen (NO_3-NO_2-N) by this assay were 0.01 mg/l.

4.3.5 Fecal and Total Coliform Bacteria Analysis

Fecal and total coliform bacteria were used as an indication of pathogens. Determination of fecal and total coliform populations were done by the Membrane Filter Technique, as described in Section 909 of Standard Methods for the Examination of Water and Wastewater (American Public Health Association, 1985). Lowest detectable levels for fecal coliform bacteria by this assay were 1 CFU/ml.

4.3.6 Harvest Sample Analysis

Grass samples taken from each of the plots were weighed to determine total sample mass. A grab sample was removed and placed into a whirl-pak bag and frozen until analysis to determine the percent dry mass could be done.

4.3.7 Risk Exposure Sample Analysis

The risk exposure samples were used to determine potential hazards associated with incidental contact of the lawn surface after application of renovated wastewater. Fecal and total coliform press-plates were prepared prior to the study and analyzed after exposure as described in Section 909 of Standard Methods for the Examination of Water and Wastewater (American Public Health Association, 1985).

The grass analysis involved cutting the grass in approximately 2.5 cm long pieces and suspending the material in a buffer solution to be shaken for 5 minutes using a wrist action shaker. The broth was then examined by the Membrane Filter Technique, as described in Section 909 of Standard Methods for the Examination of Water and Wastewater (American Public Health Association, 1985).

4.3.8 Runoff Samples

Runoff water samples were analyzed in the same manner as the samples collected from the system. The analyses and methodology are presented previously.

Runoff volumes were taken from the stage recorder charts for each of the research plots. Volumes were calculated using HS-flume data described in <u>Agricultural Handbook Number 224</u> (USDA,1979). These volumes were used with concentration data for the runoff samples to determine the mass of the various constituents in the runoff.

4.3.9 **Flow Rates**

Flow meters were used to measure the system input of septic tank effluent, sand filter loading, system output, and potable water volumes. These were read at least once per week and the values used to calculate weekly loading rates for the system.

4.4 DATA ANALYSIS

Prior to analysis of prototype performance, quality parameter values determined from the weekly-collected system samples were averaged with values from samples collected on the preceeding and succeeding week. Each value used for evaluation of prototype performance was, therefore, the mean of three observed values. A running average of this nature was selected in recognition of the fact that the renovation process in the prototype system is a dynamic biological process which is continually changing in response to its environment.

A rank mean method was used to statistically compare the environmental impact of applying RSF effluent to a lawn surface. This type of method was chosen because it is well suited to data sets with large variations in magnitude of observed values which commonly occur when enumerating bacteria for environmental samples. The bacterial exposure data for this study contained several zero observations or observations in which the number of bacteria were below the detectable limits of the enumeration procedure. The rank mean procedure was used to evaluate bacterial exposure risk, runoff water quality, and harvest yields.

The rank mean method ranks all of the data from lowest to highest and assigns an integer value starting with 0 to the lowest data value (SAS Institute Inc., 1985). The data are then analyzed by means of nonparametric statistics (statistical analysis performed on the rank value assigned to the data value instead of on the actual data value) to determine if there are significant differences. Using the rank means, standard statistical methods such as Analysis of Variance (ANOVA) may be performed. The comparisons for this project were between data sets from the system plot, water plot, and dry plot to determine the effects of applying RSF effluent to a lawn surface.

Bacterial ingestion and contact risk assessment was also analyzed statistically by using a categorical data modeling (CATMOD) procedure (SAS Institute Inc., 1987). CATMOD allows analysis of variance to be performed on response functions which represent the magnitudes of actual data values, thus presenting a comparison among plot data which accounts for the observed values. This method used the 75th percentile value (chosen arbitrarily for comparison purposes) for the fecal and total coliform bacteria observations from the water plot as a standard to compare the other plots against. The water plot observations were used because it is common practice to apply potable water to a lawn, and by using a high percentile value (75 for this comparison), a statistical comparison which showed no disadvantage between the research plots would alleviate public concern of applying renovated wastewater.

Using this 75th percentile value, data from the plots were checked to see how many observations were above the value. The number of observations above the 75th percentile for each plot were then compared statistically (within CATMOD using the chi-square method for independence) to determine if there were any significant differences among plots.

5.0 RESULTS AND DISCUSSION

The information presented in the following text is a compilation of observations from a prototype on-site domestic wastewater renovation system. Observations were made concerning nitrogen, organic carbon, and fecal bacteria removal by the system, as well as the environmental impact associated with lawn application of the renovated effluent.

The results have been divided into two basic sections. These are:

1. System Performance, and
2. Environmental Impact.

The system performance section includes hydraulic loading; nitrogen removal; COD removal; bacteria removal; mechanical reliability and power consumption; and recommended future modifications. The environmental impact section includes information on bacterial exposure; runoff quality; grass yield; and implications for wide spread use and operating modifications.

5.1 SYSTEM PERFORMANCE

The RSF system was designed to remove nitrogen, organic carbon (COD), and coliform bacteria. During the overall monitoring period there were three distinct operating periods defined by alterations in the sand filter's hydraulic loading rate.

The overall system performance was evaluated based on the system input (septic tank effluent) and system output (renovated wastewater applied to the lawn surface) parameters observed during operation. Data were collected for nitrate-nitrite-nitrogen, ammonia nitrogen, TKN, and total nitrogen (TN); COD; total and fecal coliform bacteria on a weekly basis. Data from the initial seven week start-up period were excluded from the performance evaluation.

5.1.1 Hydraulics

The RSF prototype was designed to operate with constant flow rates delivered by all three pumps. The system input was designed for a weekly flow of 2543 liters (672 gallons). Actual rates varied from 272 to 3075 liters per week (72 to 813 gallons per week) and averaged 2223 liters per week (587 gallons per week) over the entire 37 week observation period. Figure 5.1 shows the system input (septic tank effluent) and system output flow rates on a weekly basis. Variability in the flow rates for the system input generally stemmed from problems with clogging of the intake screen which was initially installed on the septic tank pump (the extremely low values occurred during periods when the residential occupants were on vacation and no wastewater was produced). A vault which allowed better control of the system input flow was installed in the septic tank during week 32. After the vault was installed, flows ranged from

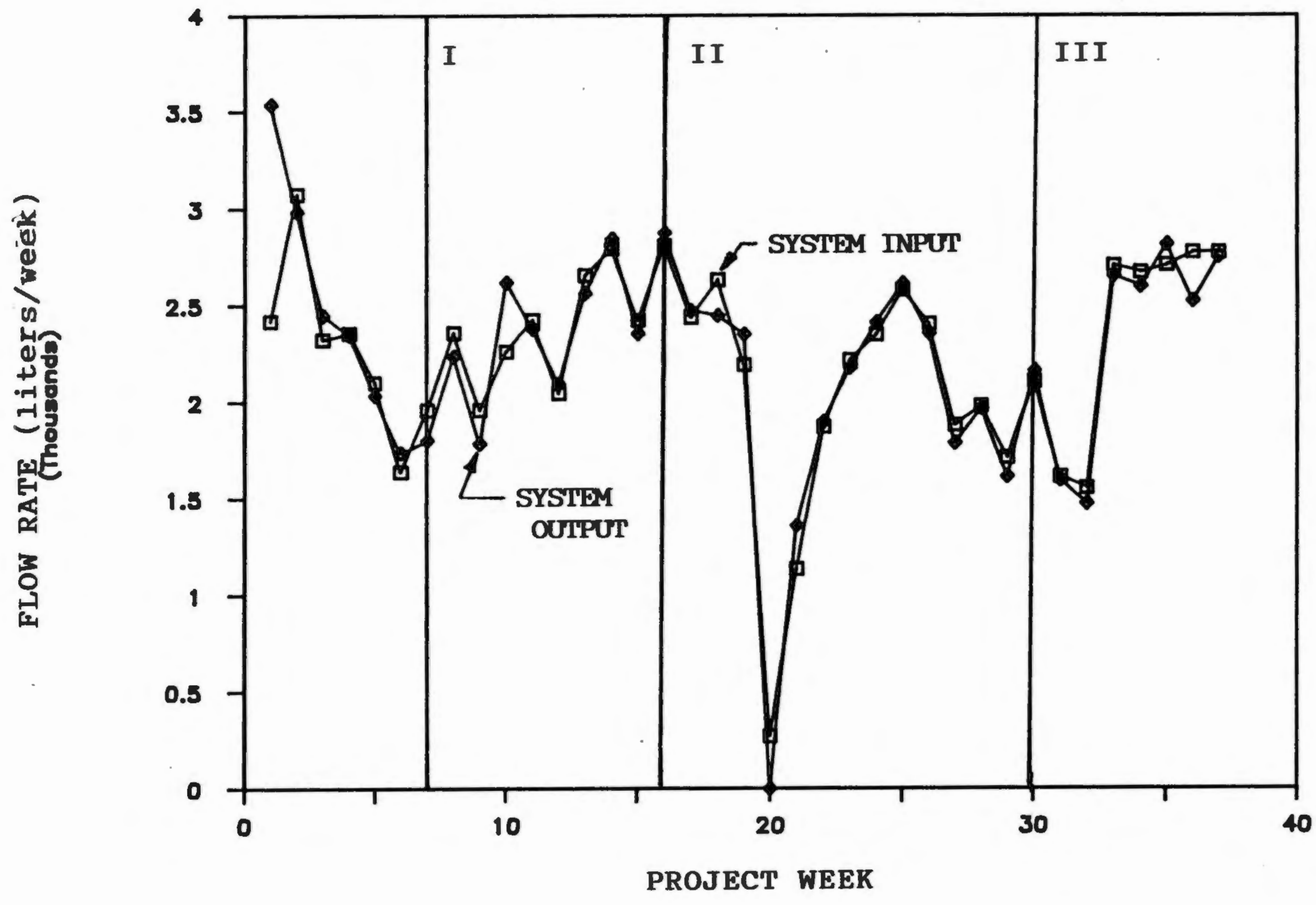

Figure 5.1 Hydraulic Flow Rates Versus Time for RSF System Input and Output

2673 to 2776 liters per week (706 to 733 gallons per week) and averaged 2728 liters per week (721 gallons per week).

The system output ranged from 1360 to 3262 liters per week (359 to 862 gallons) with an average of 2235 liters per week (591 gallons per week). Variations in the system output were directly related to the problems incurred with the intake screen on the septic pump since the discharge pump controls were set to permit only the volume added to the system to be pumped out.

Recirculation flow rates were changed twice during the observation period. Figure 5.2 shows the filter input flow and the corresponding recirculation ratio for each of the three operating periods. Between day 0 and day 113 the flow averaged 10,465 liters per week (2765 gallons per week), which was 4.4 times the average system input flow rate and thus established a recirculation ratio of 4.4:1. During the period from day 113 to day 211, the average flow was increased to 14,248 liters per week (3764 gallons per week) which resulted in a recirculation ratio of 7.3:1. After day 211 the recirculation ratio was decreased to 3.9:1 by reducing the filter hydraulic loading rate to an average of 10,057 liters per week (2657 gallons per week).

5.1.2 <u>Nitrogen Removal</u>

Samples from the RSF prototype were analyzed for ammonia, nitrate-nitrite, TKN, and total nitrogen concentrations. Nitrogen mass balances were calculated on

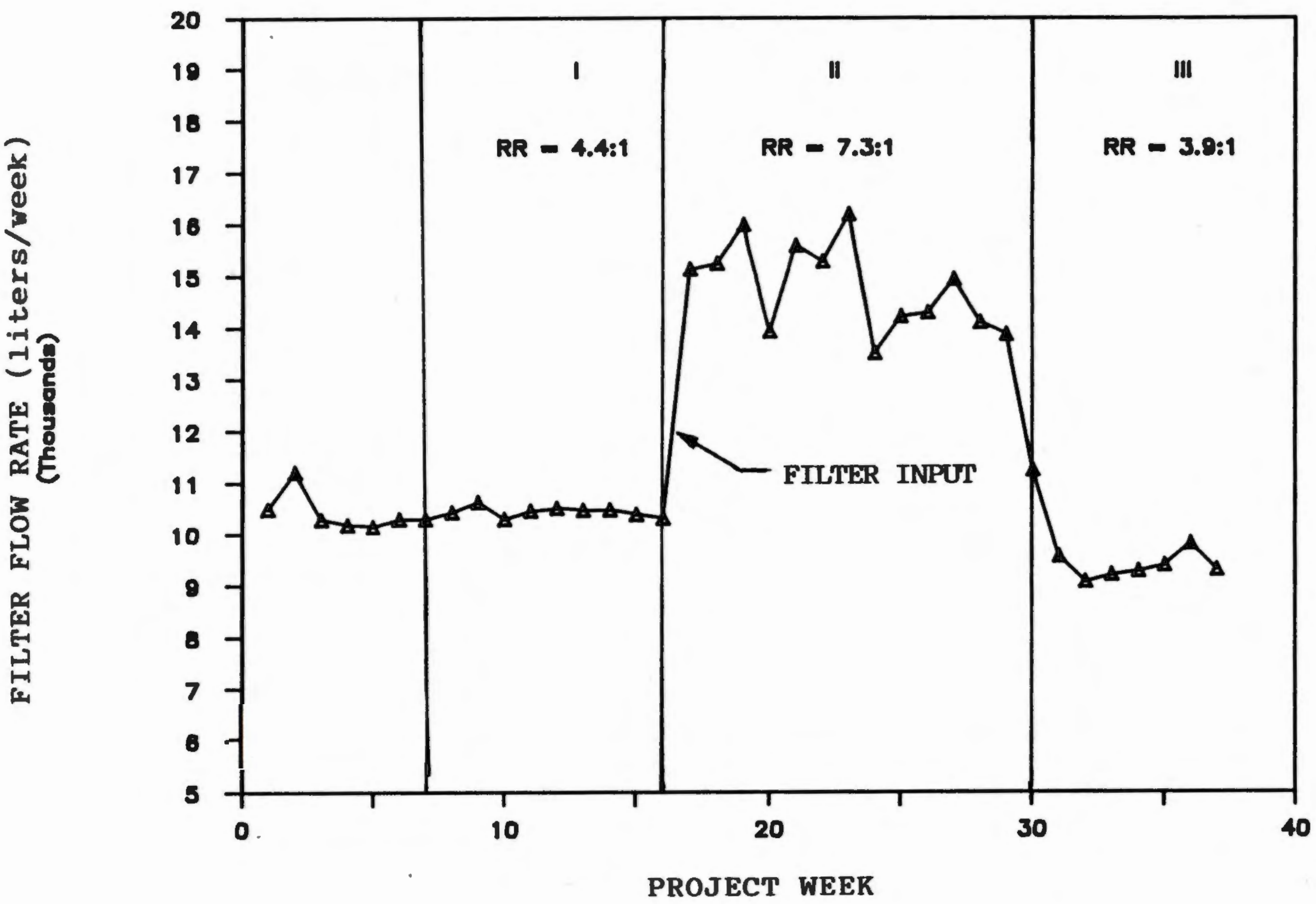

Figure 5.2 Hydraulic Flow Rate Versus Time for Sand Filter Input and Recirculation Ratios to Distinguish Operating Periods.

the overall system, the accumulation tank and the sand filter. Overall system performance was evaluated using the system input and system output values.

Figure 5.3 shows the observed total nitrogen concentrations for system input, system output and filter output. Data values for the start-up period (day 0 through 50) have been included in this graph, but were not used in any calculations.

Based on the nitrogen mass balance for the overall system, the removal efficiencies (see Figure 5.4) averaged 71.1% for period I, 82.5% for period II, and 77.0% for period III. These were calculated using the mean total nitrogen mass removed between system input and system output.

Mass balances were also performed on the accumulation tank and sand filter in order to illustrate where in the system total nitrogen was being removed. Mass balance equations were:

$$\text{System Removal} = SI - SO \qquad (14)$$

$$\text{Accumulation Tank Removal} = (SI+FO) - (SO+FI) \qquad (15)$$

$$\text{Sand Filter Removal} = FI - FO \qquad (16)$$

where,

SI = System Input
SO = System Output
FI = Filter Input
FO = Filter Output

Equations 14, 15, and 16 were used to calculate values for the mass removal of each component and these values were

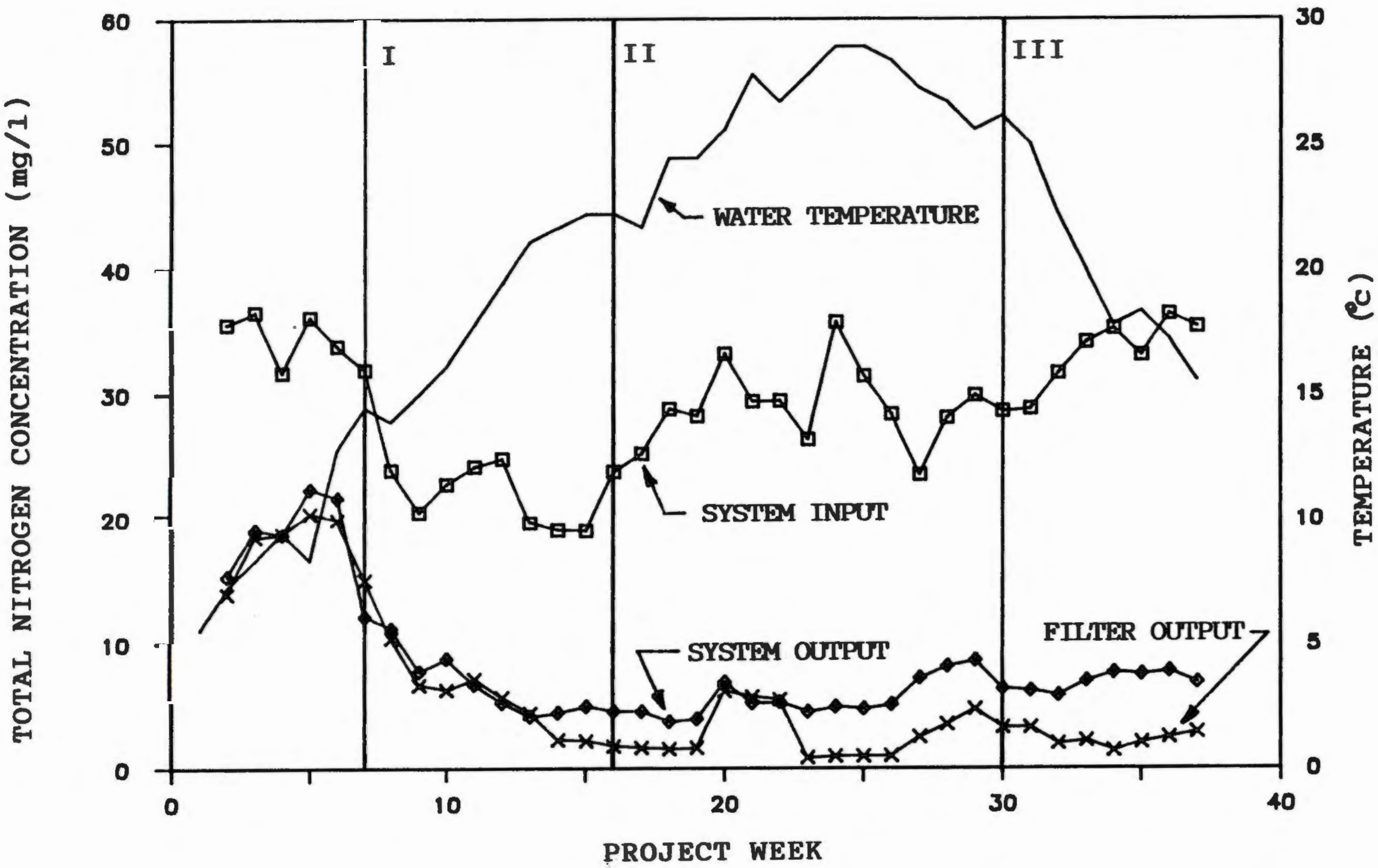

Figure 5.3 Total Nitrogen Concentration With Water Temperature Superimposed Versus Time for System Input, System Output, and Filter Output

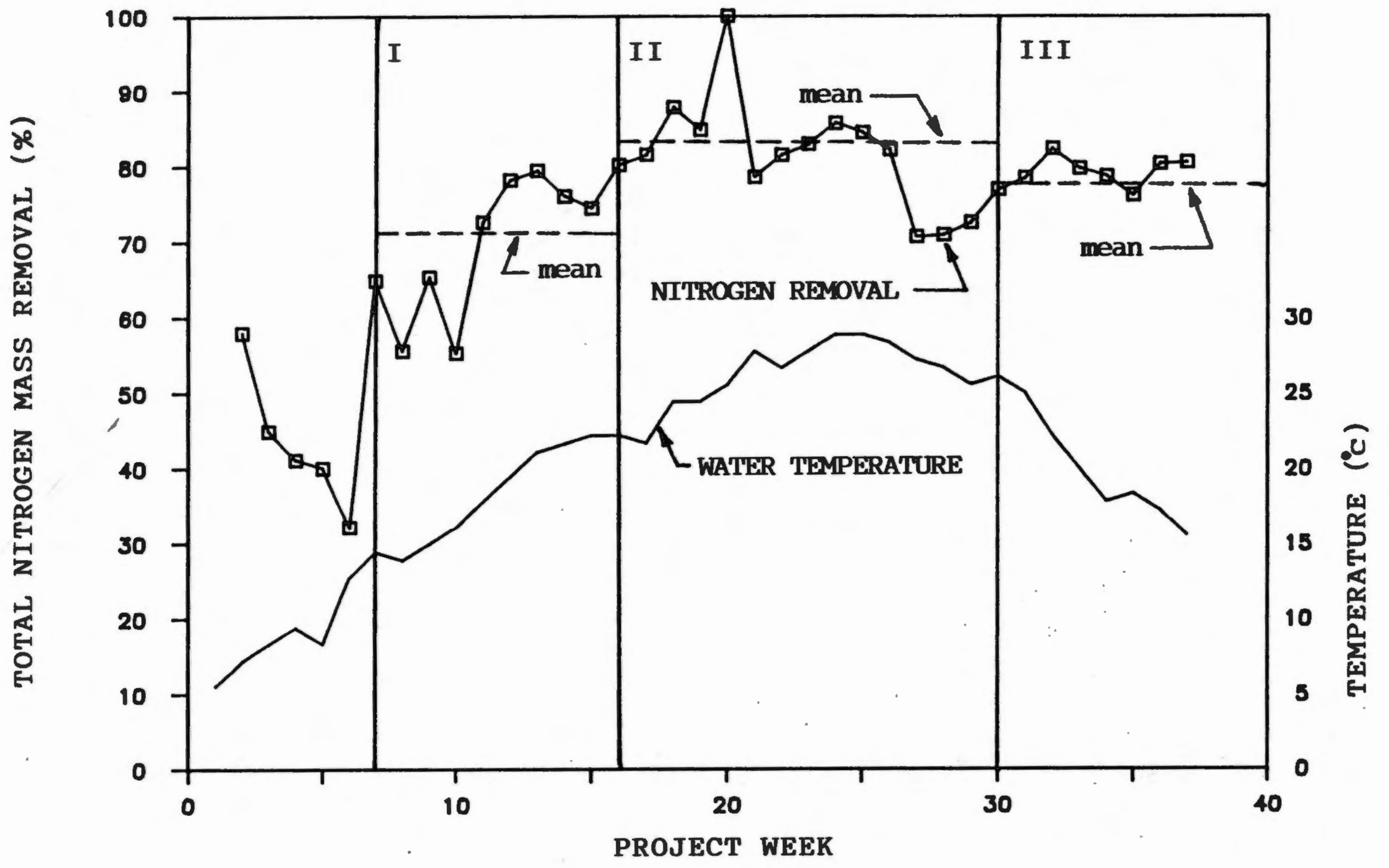

Figure 5.4 Total Nitrogen Removal With Water Temperature Superimposed Versus Time for RSF System

then used to calculate the percentage of the total amount removed in the accumulation tank and sand filter by dividing the appropriate mass removal by the overall removal. Table 5.1 shows the percentage of overall total nitrogen removal occurring in the accumulation tank and sand filter for operating periods I, II, and III. The results indicate that the sand filter was primarily responsible for removal of total nitrogen in the RSF system.

During period I the system and filter output total nitrogen concentrations dropped consistently and levelled off near the end of the period (see Figure 5.3). The output values remained relatively constant until week 26 when an increasing trend began. The change beginning at week 26 is also reflected in a decrease of removal efficiency as indicated in Figure 5.4. The change was attributed to the increased carbon removal which occurred at the higher recirculation rate. The organic carbon (COD) concentration dropped to nearly zero in the system output and the filter output during this period (Figure 5.5 and 5.6). The lack of a carbon source caused a substantial decrease in the denitrification efficiency and allowed a higher concentration of nitrogen in the form of nitrate-nitrite in the filter output (Figure 5.5). During period III the nitrate-nitrite nitrogen concentration declined and COD increased to values near those in period I.

Table 5.1 Percentage of System Total Nitrogen Removal Occurring in the Accumulation Tank and Sand Filter

	Percentage of Total Nitrogen Removed by Component	
Period	Sand Filter	Accumulation Tank
I	86.7	13.3
II	97.9	2.1
III	68.1	31.9

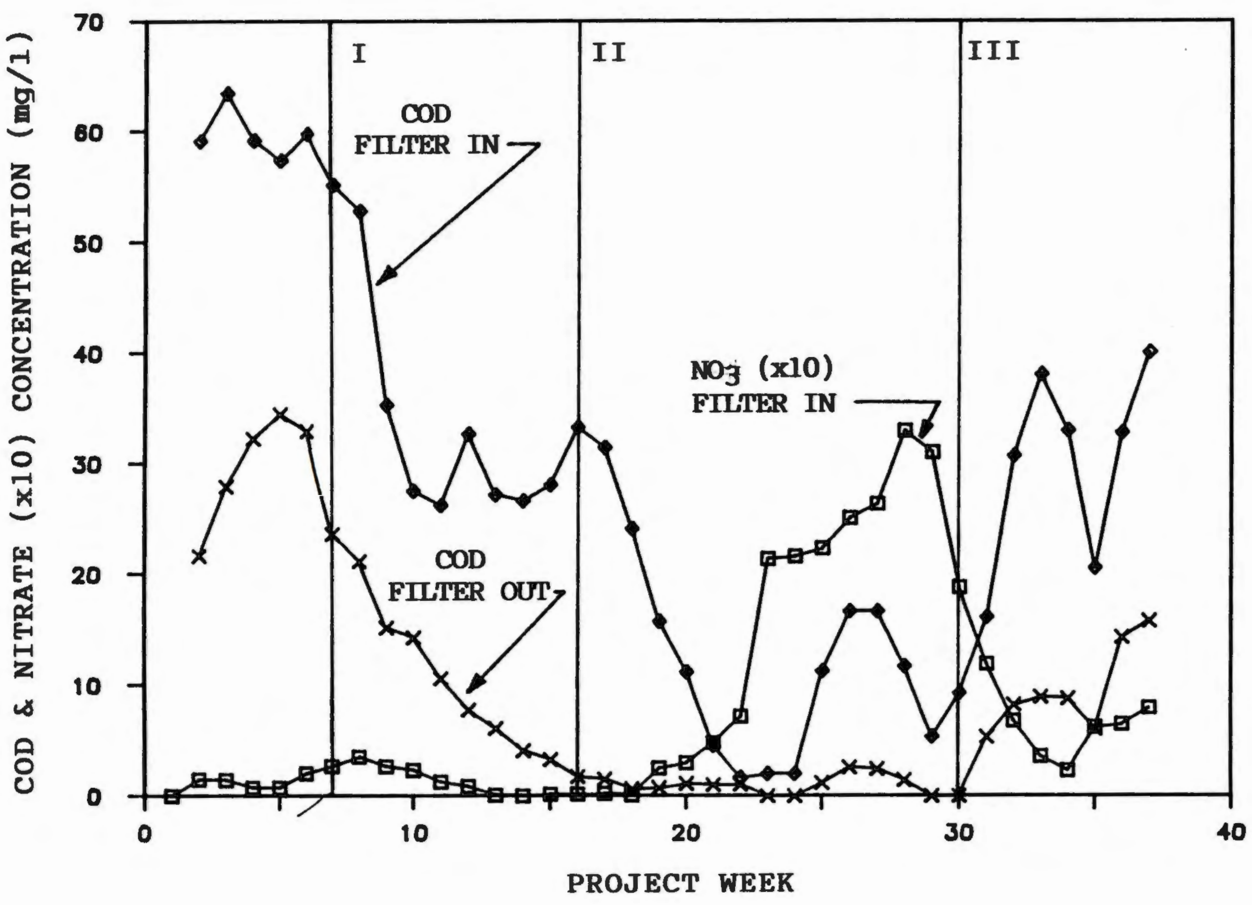

Figure 5.5 COD and Nitrate Concentration Comparison for the Sand Filter Versus Time

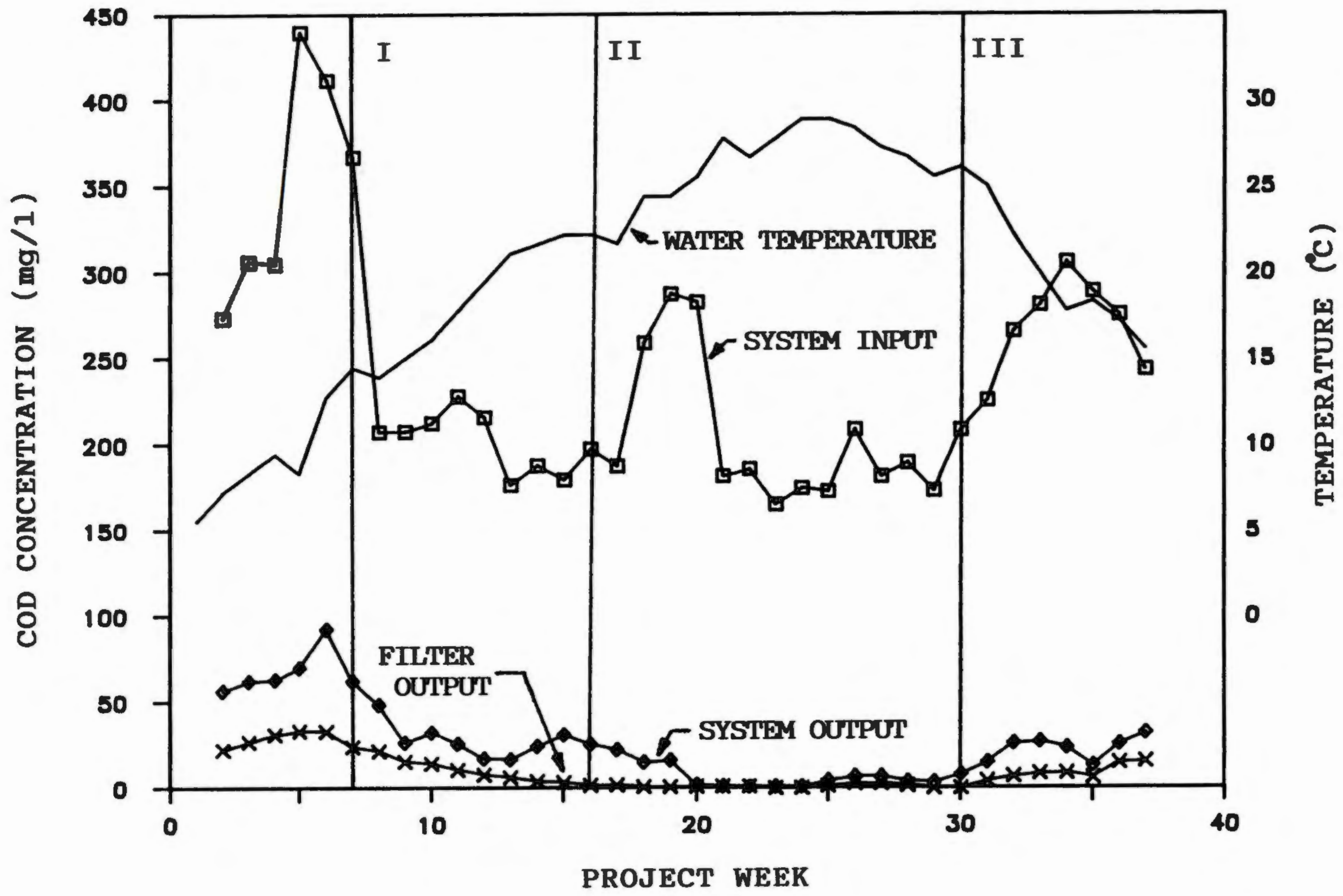

Figure 5.6 COD Concentration With Water Temperature Superimposed Versus Time for System Input, System Output, and Filter Output

5.1.3 Organic Carbon (COD) Removal

The RSF prototype was also monitored for its COD removal. Figure 5.6 shows the COD concentrations for system input, system output, and filter output. Based on the COD mass balance for the overall system, the removal efficiencies averaged (computed as system removal divided by system input multiplied by 100%) 86.3% for period I, 96.3% for period II, and 91.6% for period III. Figure 5.7 shows the removal efficiency on a weekly basis.

The high removal noticed during period II was probably caused by the increased recirculation ratio and the higher water temperature. It is not clear from these observations whether the removal efficiency was influenced more by recirculation rate or temperature.

As with nitrogen, the filter output again exhibited lower concentrations than the system output, except for weeks 21 through 24 when the two outputs were nearly equal. The COD concentration in the output streams was also very stable and did not respond to short-term fluctuations in input COD concentrations.

Table 5.2 shows the distribution of COD removal between the accumulation tank and sand filter. The percent of total COD removed in each component was determined by dividing the accumulation tank or sand filter removal by the overall system removal and multiplying by 100%. The accumulation tank accounted for more COD removal than was expected.

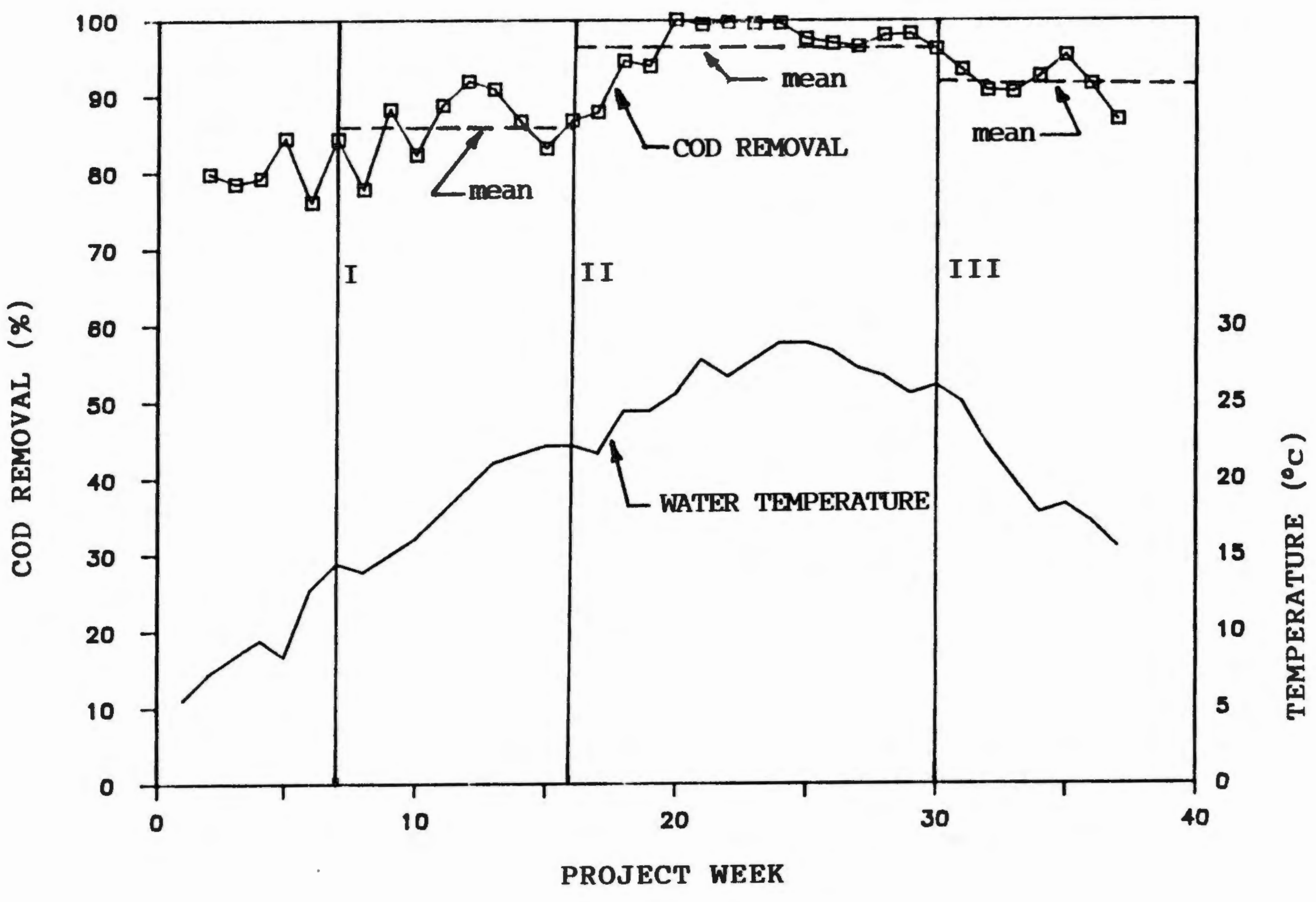

Figure 5.7 COD Removal With Water Temperature Superimposed Versus Time for RSF System.

Table 5.2 Percentage of Total COD Removed in the Accumulation Tank and Sand Filter

Period	Percentage of COD Removed by Component	
	Sand Filter	Accumulation Tank
I	57.0	43.0
II	40.7	59.3
III	32.6	67.4

Apparently, significant carbon oxidation occurred in the accumulation tank.

5.1.4 Coliform Bacteria Removal

Fecal and total coliform bacteria removal is the final RSF prototype performance parameter to be discussed. Due to the large population values, removal has been presented on a log scale rather than as percentages. Figure 5.8 illustrates the fecal coliform bacterial content (log CFU/ml) for system input, system output, and filter output, while Figure 5.9 illustrates the corresponding data for total coliform bacteria. Both graphs have similar shapes and show that the bacterial content of system and filter output is lower than, but generally parallel to the number of bacteria input to the system.

The fecal coliform bacteria removal is shown in Table 5.3. By using the mean values for total number of organisms, it can be seen that the overall system produced a fecal coliform bacteria log reduction of 1.3 for period I, 2.8 for period II, and 0.5 for period III. In order to compare the number of bacteria in the filter output on a common basis with the number of bacteria in the system input, the weekly concentration of coliform bacteria in the filter output was multiplied by the weekly flow for the system to get a projected filter output. This provided a comparison to illustrate the significant advantage of using the filter output as discharge from the RSF system. The

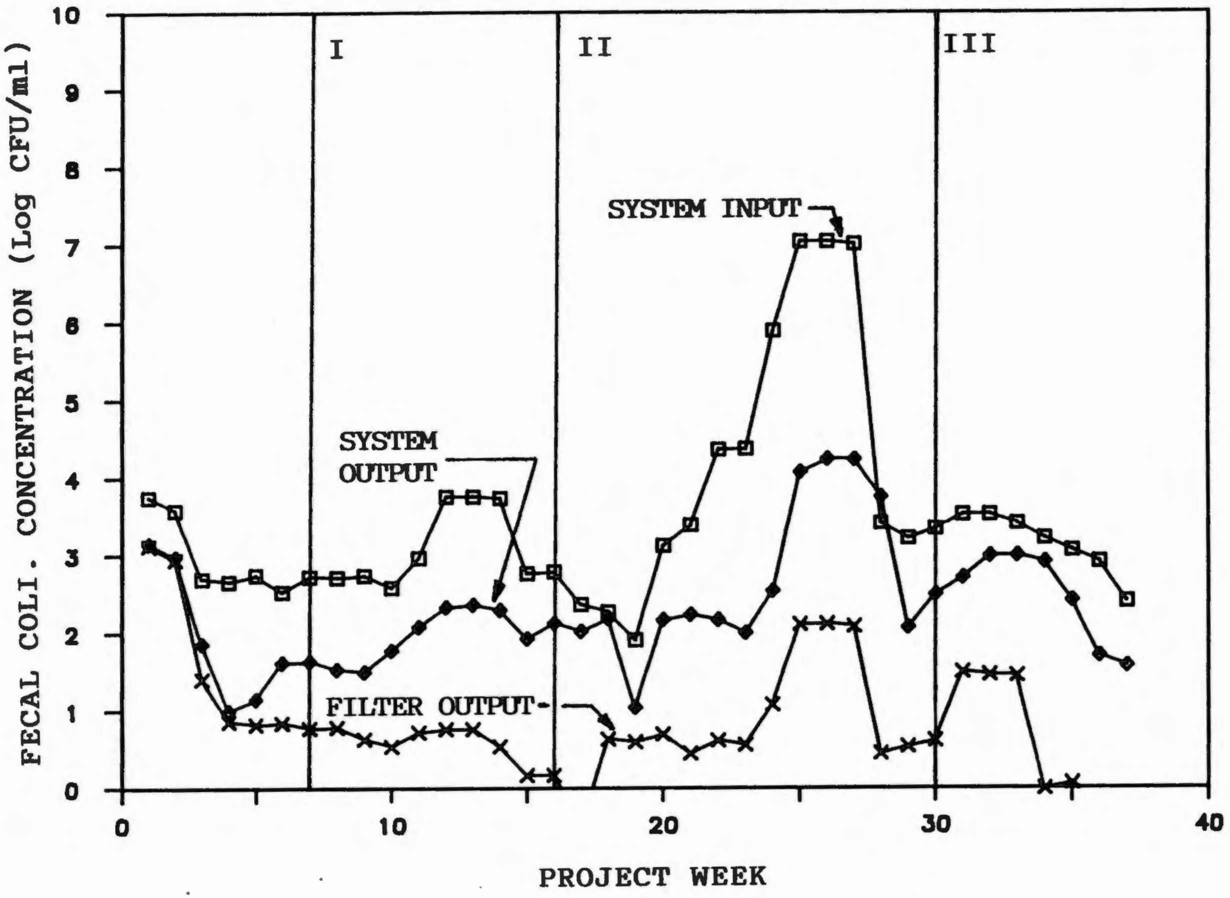

Figure 5.8 Fecal Coliform Bacterial Concentration (Log CFU/ml) Versus Time for System Input, System Output, and Filter Output

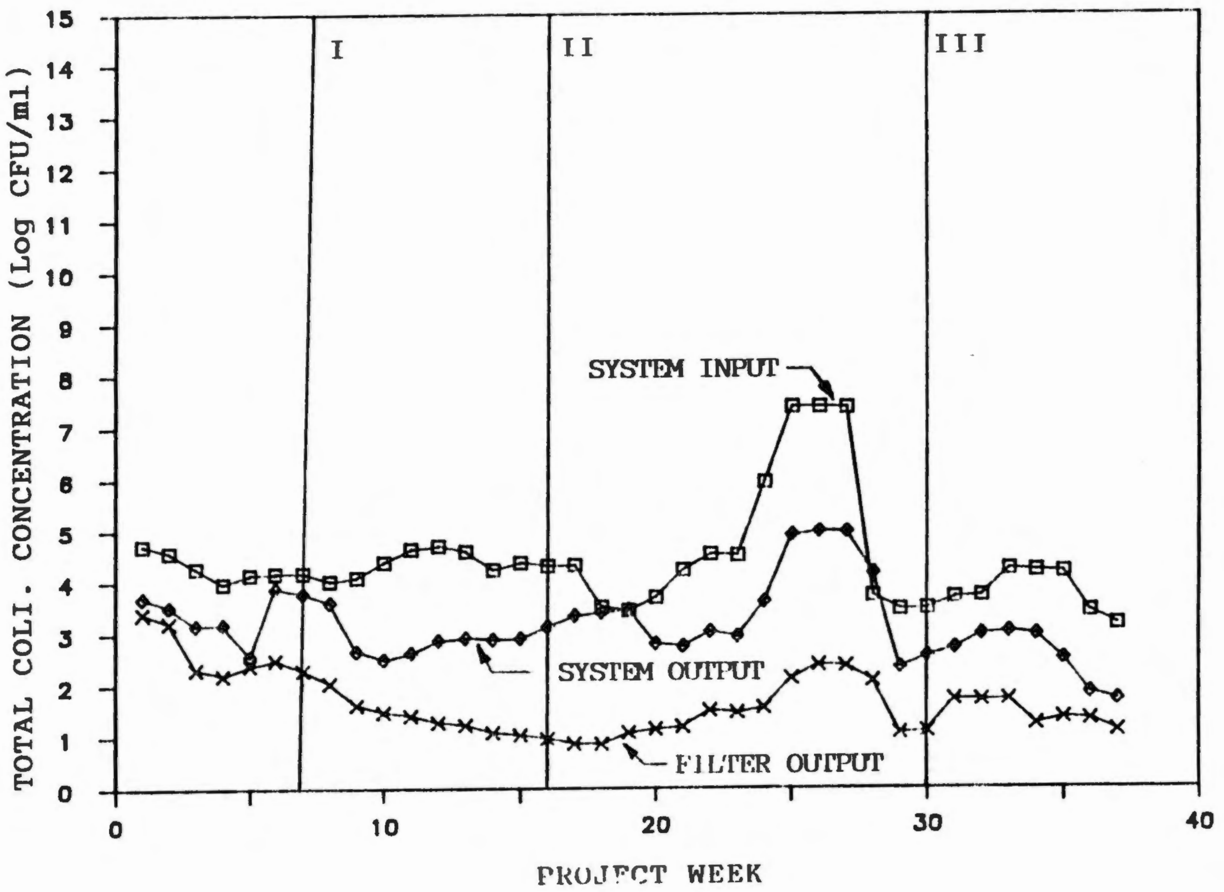

Figure 5.9 Total Coliform Bacterial Concentration (Log CFU/ml) Versus Time for System Input, System Output, and Filter Output

Table 5.3 Mean Fecal Coliform Bacterial Content Log Reduction for System Input, System Output, and Projected Filter Output

Period	System Input	System Output		Projected Filter Output[a]	
	Mean (log CFU[b]/wk)	Mean (log CFU/wk)	Reduction[c] (log CFU/wk)	Mean (log CFU/wk)	Reduction (log CFU/wk)
I	9.8	8.5	1.3	7.0	2.8
II	12.7	9.9	2.8	7.8	4.9
III	9.6	9.1	0.5	7.4	2.2

[a] Projected filter output is determined by multiplying the filter output bacterial concentration by the system flow rate. This allows a comparison between the quality of system input and filter output quality.

[b] CFU = colony forming unit.

[c] Reduction determined as difference between input and output.

projected filter output performed much better with reductions of 2.8, 4.9, and 2.2, respectively.

Total coliform values are shown in Table 5.4, and illustrate the same trends noted with the fecal coliform bacteria. Coliform bacteria removal observations indicate that fewer coliform bacteria would be released to the environment if system discharge were to be taken only from the filter output.

5.1.5 Mechanical Reliability and Power Consumption

The RSF prototype operated well from a standpoint of reliability. The major problem with operation was associated with the septic tank pump, which would not normally be present in a full scale system. Frequent clogging of the pump intake filter reduced input flow rates and necessitated cleaning of the filter at short intervals. After a screened vault was placed around the pump, flow rates remained stable without frequent cleaning.

On April 22, 1988, after 60 days of operation, the sand filter was rebuilt after the nylon mesh sock surrounding the 2-inch nominal diameter PVC drain was removed. The nylon sock was removed because it clogged with fine soil particles from the river sand initially placed in the filter. Performance suggests that there is no justification for a fine-mesh envelope around underdrain lines.

The recirculation pump (located in the accumulation tank) was defective and had to be replaced on July 7, 1988.

Table 5.4 Mean Total Coliform Bacterial Content Log Reduction for System Input, System Output, and Projected Filter Output

Period	System Input	System Output		Projected Filter Output[a]	
	Mean (log CFU[b]/wk)	Mean (log CFU/wk)	Reduction[c] (log CFU/wk)	Mean (log CFU/wk)	Reduction (log CFU/wk)
I	10.8	9.4	1.4	7.9	2.9
II	13.1	10.7	2.4	8.2	4.9
III	10.4	9.1	1.3	7.9	2.5

a Projected filter output is determined by multiplying the filter output bacterial concentration by the system flow rate. This allows a comparison between the quality of system input and filter output quality.

b CFU = colony forming unit.

c Reduction determined as difference between input and output.

A crack developed in the pump housing, and the resulting electrical short circuit was sufficient to trip the ground fault interrupter and sound the alarm to alert the homeowner of a potential problem.

Even with the few mechanical problems, the RSF required very little maintenance on a day-to-day basis. The in-line filters were cleaned approximately monthly and were seldom to a point where it was critical at that time. During the operating period, from February to November, the sand filter never required routine maintenance to keep it working properly.

Power consumption remained relatively constant throughout the duration of the project. During normal operation the RSF prototype used 12.5 kWh of electricity per week.

5.1.6 Future Modifications

Results from the RSF prototype indicate some modifications which may enhance the performance of future systems. One prominent modification suggested by the results is to change system flow paths so that the system output can be taken entirely from filter discharge that has not been mixed with untreated septic tank effluent. Figures 5.3, 5.6, 5.8, and 5.9 show that the filter output consistently had more favorable quality parameters than did the system output.

Tables 5.3 and 5.4 strongly support the modification to take the system output from the filter discharge. The projected filter output value of 7.9 log CFU/wk (Table 5.3) corresponds to a fecal coliform concentration of 3550 CFU's/100 ml, while the value of 7.0 log CFU/wk corresponds to a fecal coliform concentration of only 447 CFU's/100 ml. These concentrations are equal to or less than those found for field distribution from a typical waste treatment process as listed in Table 2.3. The actual bacterial concentrations for fecal coliforms from the filter output are also in the water quality range listed in Section 2.7 for primary contact sports. Nitrogen and COD concentrations from the filter discharge also support the modification. Nitrogen concentrations (Figure 5.3) stayed well below 10 mg/l, and COD concentrations (Figure 5.6) remained near zero for much of the time.

A second suggested modification is to maintain the entire filter freely drained and incorporate a small denitrification chamber to receive the nitrified water returning from the sand filter and the raw septic tank effluent entering the system. This will make all of the organic carbon in the septic tank effluent available to provide energy for the denitrification process. Such a modification has the potential for significantly increasing the nitrogen removal ability of the system.

5.2 ENVIRONMENTAL IMPACT

Environmental impact assessment was based on bacterial exposure, and runoff samples, as well as on harvest yields from each of the study plots. Bacterial exposure samples were taken once during each season (approximately every three months). Runoff samples were taken each time precipitation produced runoff during the operating period. Harvest yields were taken at various times during the growing season, when the plots were mowed.

5.2.1 Bacterial Exposure

Bacterial exposure was studied in terms of contact exposure and ingestion exposure. Contact exposure was determined using the press-plate method described earlier and was considered to represent the coliform bacterial exposure resulting from incidental contact with the grass. Ingestion exposure was determined by extracting coliform bacteria from grass samples as described earlier, and was considered to represent the exposure resulting from direct ingestion of grass after application of system effluent.

5.2.1.1 Bacterial Die-Off

Rank mean data for contact and ingestion exposure were first analyzed to detect any significant die-off over time (after irrigation) for either fecal or total coliform bacteria. The data were separated by season and statistically analyzed to compare number of colony forming units (per unit area for contact exposure and per unit mass of dry grass for ingestion exposure) versus time after application. At the 0.05 probability level there were no differences among the observed values with respect to time (i.e. there was no evidence of a die-off curve) except in the case of contact exposure to total coliform bacteria during the fall sampling. This finding is contradictory to the results reported by Scherer and Mitchell (1982), in which they reported an exponential decline in the number of bacteria after application.

5.2.1.2 <u>Contact Exposure</u>

Contact exposure, resulting from incidental contact with a lawn surface after application of renovated wastewater, was analyzed using statistical comparisons between the three research plots. Table 5.5 summarizes the results of the statistical procedure used to compare the coliform bacteria rank means for the system versus dry plot and system versus water plot. An evaluation of the comparisons (Table 5.6) indicates that there was increased risks of contact exposure in the fall and spring seasons, but no apparent disadvantage during the summer months.

Results of the comparison between the number of observations greater than the 75th percentile observation for the water plot are summarized in Table 5.7. An evaluation of the comparisons (Table 5.8) leads to the same conclusions suggested previously by the rank mean data

Table 5.5 Summary of Seasonal Plot Coliform Bacteria Contact Exposure Comparison by Rank Mean Method

Comparison	Fecal Coliform RANK[a] MEAN	Fecal Coliform Pr[b]	Total Coliform RANK[a] MEAN	Total Coliform Pr[b]
SPRING				
SYSTEM	N.D.	N.D.	49.32	4E-07
WATER	N.D.		22.98	
SYSTEM	N.D.	N.D.	49.32	2E-05
DRY	N.D.		28.20	
SUMMER				
SYSTEM	49.13	.0003	44.33	.0567
WATER	26.08		32.10	
SYSTEM	49.13	.3340	44.33	.7218
DRY	43.28		42.08	
FALL				
SYSTEM	58.83	3E-07	59.25	5E-05
WATER	32.94		45.06	
SYSTEM	58.83	2E-09	59.25	4E-19
DRY	26.73		14.19	

Rank Mean Comparison of Coliform Bacteria

a A greater rank mean value indicates a greater number of observations for which a greater number of bacteria per unit area were observed.

b Probability that difference of the magnitude observed could have occurred solely by chance.

c N.D. signifies no data for analysis. No fecal coliform bacteria were detected, however no positive control was used to verify the absence of fecal coliform bacteria.

Table 5.6 Evaluation of Seasonal Plot Contact Exposure Comparisons by Rank Mean Method

Parameter	Comparison of Contact Exposure Risk from System Plot Versus Control Plots	
	No Disadvantage[a]	Disadvantage[b]
---------- SPRING ----------		
FECAL COLIFORM	--[c]	--
TOTAL COLIFORM		X
---------- SUMMER ----------		
FECAL COLIFORM	X	
TOTAL COLIFORM	X	
---------- FALL ----------		
FECAL COLIFORM		X
TOTAL COLIFORM		X

a At 0.05 probability level, the indicated number of bacteria per unit area from the system plot was either no different or less than the number from one or both control plots.

b At 0.05 probability level, the indicated number of bacteria per unit area from the system plot was greater than the number from both control plots.

c No data for comparison, due to lack of a positive control to verify any fecal coliform bacteria present.

Table 5.7 **Summary of Comparisons Between the Numbers of Contact Exposure Observations That Were Greater Than the 75th Percentile Observation for the Water Plot**

Plot	Fecal Coliform Standard[a] (CFU/in^2)	Fecal Coliform Number of Obs. greater than standard	Fecal Coliform Pr[b]	Total Coliform Standard (CFU/in^2)	Total Coliform Number of Obs. greater than standard	Total Coliform Pr
SPRING						
Water	N.D.	N.D.[c]	N.D.	0.49	6 of 22	0.0007
System		N.D.			18 of 22	
Dry	N.D.	N.D.	N.D.	0.49	9 of 22	0.0077
System		N.D.			18 of 22	
SUMMER						
Water	13.30	7 of 26	0.1537	22.80	7 of 26	0.0014
System		12 of 26			19 of 26	
Dry	13.30	10 of 26	0.5750	22.80	16 of 26	0.3770
System		12 of 26			19 of 26	
FALL						
Water	2.78	7 of 26	0.0276	4.69	7 of 26	0.0006
System		15 of 26			20 of 26	
Dry	2.78	0 of 26	0.0040	4.69	2 of 26	0.0000
System		15 of 26			20 of 26	

[a] Standard is the 75th percentile observation for water plot (i.e., 75% of the observed values from the water plot were less than or equal to the standard).

[b] Probability that difference between numbers of observations greater than the standard could have occurred solely by chance.

[c] N.D.: no comparison possible due to lack of data.

Table 5.8 Evaluation of Comparison of Seasonal Plot Contact Exposure Observations Using the 75th Percentile Observation for the Water Plot as a Standard

	Comparison of Contact Exposure Risk from System Plot Versus Control Plot	
Parameter	No Disadvantage[a]	Disadvantage[b]
SPRING		
FECAL COLIFORM	--[c]	--
TOTAL COLIFORM		X
SUMMER		
FECAL COLIFORM	X	
TOTAL COLIFORM	X	
FALL		
FECAL COLIFORM		X
TOTAL COLIFORM		X

a At the 0.05 probability level, the number of times that the observed coliform bacteria per unit area on the system plot exceeded the standard was either no different or less than the number of times the standard was exceeded on one or both control plots.

b At the 0.05 probability level, the number of times that the observed coliform bacteria per unit area on the system plot exceeded the standard was greater than the number of times the standard was exceeded on both control plots.

c No data for comparison.

analysis. Surface application of treated wastewater created increased risks for contact exposure to coliform bacteria during spring and fall, but no disadvantage during the summer season. The latter finding may be significant because the highest chance of incidental contact would occur during the warmer months when people are likely to spend more time on the lawn.

5.2.1.3 Ingestion Exposure

Ingestion exposure data were analyzed in the same manner as contact exposure data to determine the risk of ingestion of coliform bacteria. Table 5.9 shows the rank mean results comparing the research plots during three different seasons. An evaluation of the comparisons (Table 5.10) indicates that, with the exception of fecal coliform bacteria during the spring season, there was no disadvantage when comparing the system plot to the control plots for bacterial ingestion exposure.

Results of the comparison between the number of observations greater than the 75th percentile observation for the water plot are summarized in Table 5.11. An evaluation of the comparisons (Table 5.12) leads to much the same conclusions suggested by the rank mean data analysis. Surface application of treated wastewater showed no disadvantage during any of the seasons.

Table 5.9 Summary of Seasonal Plot Coliform Bacteria Ingestion Exposure Comparison by Rank Mean Method

Comparison	Rank Mean Comparison of Coliform Bacteria			
	Fecal Coliform		Total Coliform	
	RANK[a] MEAN	Pr[b]	RANK MEAN	Pr
SPRING				
SYSTEM	33.50	.7264	49.95	3E-10
WATER	31.36		25.45	
SYSTEM	33.50	.7264	49.95	2E-10
DRY	35.64		25.09	
SUMMER				
SYSTEM	27.46	.0017	42.61	.9759
WATER	48.48		42.42	
SYSTEM	27.46	.0210	42.61	.1541
DRY	42.56		33.46	
FALL				
SYSTEM	50.09	.3532	53.23	.1469
WATER	43.44		45.81	
SYSTEM	50.09	6E-05	53.23	2E-08
DRY	24.96		19.46	

a A greater rank mean value indicates a greater number of observations for which a greater number of bacteria per unit mass of grass were observed.

b Probability that differences of the magnitude observed could have occurred solely by chance.

Table 5.10 Evaluation of Seasonal Plot Ingestion Exposure Comparisons by Rank Mean Method

	Comparison of Ingestion Exposure Risk from System Plot Versus Control Plots	
Parameter	No Disadvantage[a]	Disadvantage[b]
SPRING		
FECAL COLIFORM		X
TOTAL COLIFORM	X	
SUMMER		
FECAL COLIFORM	X	
TOTAL COLIFORM	X	
FALL		
FECAL COLIFORM	X	
TOTAL COLIFORM	X	

a At 0.05 probability level, the indicated number of bacteria per unit mass of grass from the system plot was either no different or less than the number from one or both control plots.

b At 0.05 probability level, the indicated number of bacteria per unit mass of grass from the system plot was greater than the number from both control plots.

Table 5.11 Summary of Comparisons Between the Numbers of Ingestion Exposure Observations That Were Greater Than the 75th Percentile Observation for the Water Plot

Plot	Fecal Coliform Standard[a] (CFU/in^2)	Fecal Coliform Number of Obs. greater than standard	Fecal Coliform Pr[b]	Total Coliform Standard (CFU/in^2)	Total Coliform Number of Obs. greater than standard	Total Coliform Pr
SPRING						
Water		22 of 22			6 of 22	
	0.00E00		N.C.[c]	2.54E05		0.5185
System		22 of 22			8 of 22	
Dry		22 of 22			8 of 22	
	0.00E00		N.C.	2.54E05		1.0000
System		22 of 22			8 of 22	
SUMMER						
Water		7 of 26			7 of 26	
	1.27E06		0.7490	2.59E07		0.0482
System		6 of 26			0 of 26	
Dry		7 of 26			5 of 26	
	1.27E06		0.7490	2.59E07		0.0961
System		6 of 26			0 of 26	
FALL						
Water		7 of 26			7 of 26	
	6.80E06		0.2467	1.28E08		0.7597
System		11 of 26			8 of 26	
Dry		1 of 26			2 of 26	
	6.80E06		0.0079	1.28E08		0.0489
System		11 of 26			20 of 26	

[a] Standard is the 75th percentile observation for water plot (i.e., 75% of the observed values from the water plot were less than or equal to the standard).

[b] Probability that difference between numbers of observations greater than the standard could have occurred solely by chance.

[c] N.C.: no comparison possible because standard equal zero.

Table 5.12 Evaluation of Comparison of Seasonal Plot Ingestion Exposure Observations Using the 75th Percentile Observation for the Water Plot as a Standard

	Comparison of Ingestion Exposure Risk from System Plot Versus Control Plot	
Parameter	No Disadvantage[a]	Disadvantage[b]
------------------------ SPRING ------------------------		
FECAL COLIFORM	--[c]	--
TOTAL COLIFORM	X	
------------------------ SUMMER ------------------------		
FECAL COLIFORM	X	
TOTAL COLIFORM	X	
------------------------ FALL ------------------------		
FECAL COLIFORM	X	
TOTAL COLIFORM	X	

[a] At the 0.05 probability level, the number of times that the observed coliform bacteria per unit mass of grass on the system plot exceeded the standard was either no different or less than the number of times the standard was exceeded on one or both control plots.

[b] At the 0.05 probability level, the number of times that the observed coliform bacteria per unit mass of grass on the system plot exceeded the standard was greater than the number of times the standard was exceeded on both control plots.

[c] No comparison because the standard was equal to zero.

5.2.1.4 Summary

Two separate methods were used to assess the potential for exposure to coliform bacteria as a result of applying renovated wastewater onto a lawn surface. The contact exposure assessment showed that during the summer months there was no significant disadvantage when comparing the system plot to the two control plots. However, during the spring and fall months there was a disadvantage from this comparison. Ingestion exposure showed that with the exception of one isolated instance there was no disadvantage to applying renovated wastewater to a lawn surface.

It is not clear which test represents the worst case scenario to humans. The ingestion exposure data suggested no significant differences among the research plots (with the exception of the one isolated instance), without regard to the season. However, the contact exposure data suggested that differences occurred among the research plots during the spring and fall months but not during the warmer summer months. This may be significant, since the warmer summer months are probably when more humans would frequently contact the grass.

5.2.2 Runoff Quality

Runoff water samples were taken each time a precipitation event produced runoff from at least one of the study plots. The quantity of each water quality parameter that came off each of the study plots was calculated by multiplying the concentration (from the composite sample) of each parameter by the volume of runoff. Dates and volumes are listed in Table 5.13 for all precipitation events which produced runoff.

Table 5.14 shows the means and standard deviations (from a total of 15 samples) for each quality parameter in the runoff from each of the plots during the operating period. The system plot had lower mean values for all parameters except in the case of total coliforms. Total coliforms from the system plot were higher than from the dry plot, but considerably lower than from the water plot.

Rank means were computed and used to check for statistically significant differences in runoff quality among the three plots. Table 5.15 shows the rank mean and probability values for the various comparisons. An evaluation of the comparisons of rank mean values (Table 5.16) revealed no disadvantage, with respect to any quality parameter, to the application of treated wastewater onto the lawn plot.

Composite runoff samples from each of the plots were collected using 2-liter beakers and allowing the excess water to overflow. It would seem that the water coming off of the plots in the latter stages would have less contaminants. However, the data showed that the runoff from the water plot (with 6 events where the beaker overflowed) had considerably higher quantities of pollutants removed in

Table 5.13 Precipitation Events Which Produced Runoff From the Research Plots

Date	Precipitation (cm)
April 4, 1988	1.27
April 19, 1988	1.02
April 20, 1988	2.03
May 5, 1988	3.30
May 24, 1988	0.51
May 25, 1988	1.74
July 12, 1988	1.91
July 13, 1988	5.21
July 21, 1988	3.43
August 4, 1988	2.79
September 4, 1988	5.46
September 16, 1988	2.03
October 28, 1988	1.65
November 4, 1988	2.79
November 6, 1988	0.89

Table 5.14 Summary of Plot Runoff Quality Parameters

Parameter	DRY		SYSTEM		WATER	
	MEAN[a]	S[b]	MEAN	S	MEAN	S
VOLUME (L)	1.64	4.64	1.04	1.90	7.71	18.04
NH_3-N (MG)	4.22	9.67	0.97	2.20	8.38	20.68
NO_3-NO_2-N (MG)	1.20	3.62	1.14	1.98	7.48	23.73
TOTAL N (MG)	8.53	17.90	3.58	7.56	5.43	5.00
COD (MG)	648.46	2454.15	59.62	133.82	575.89	1819.65
F.COLI. (CFU)	621.56	1792.49	194.72	556.34	1642.19	3023.58
T.COLI. (CFU)	1532.90	3435.70	1810.31	3295.86	45588.63	112729.49

[a] Mean values were obtained by averaging values on a per event basis.

[b] Standard deviation.

Table 5.15 Comparison of Rank Mean Values for Runoff Quality Parameters

	Rank Mean Values[a] for Runoff Quality Parameters					
	Comparison 1			Comparison 2		
Parameter	System	Water	Pr[b]	System	Dry	Pr
VOLUME	18.87	30.90	.0002	18.87	19.23	.8966
NH_3-N	18.07	29.43	.0013	18.07	21.50	.2912
NO_3-NO_2-N	21.47	27.73	.0729	21.47	19.80	.6240
TOTAL N	18.63	28.53	.0187	18.63	21.83	.4267
COD	20.13	29.67	.0031	20.13	19.20	.7538
F. COLI.	21.87	26.47	.1820	21.87	20.67	.7237
T. COLI.	22.00	26.27	.2058	22.00	20.73	.7053

a A greater rank mean value indicates a greater number of observations for which the observed parameter had a greater value.

b Probability that differences in rank mean values of the magnitude observed occured solely by chance.

Table 5.16 Evaluation of Plot Runoff Quality Parameter Comparisons by Rank Mean Method

	Comparison of Runoff Quality from System Plot Versus Control Plot	
Parameter	No Disadvantage[a]	Disadvantage[b]
VOLUME	X	
NH_3-N	X	
NO_3-NO_2-N	X	
TOTAL NITROGEN	X	
COD	X	
FECAL COLIFORM	X	
TOTAL COLIFORM	X	

[a] At 0.05 probability level, the value of the runoff parameter from the system plot was either no different or less than the value of the runoff parameter from one or both control plots.

[b] At 0.05 probability level, the value of the runoff parameter from the system plot was greater than the value of the runoff parameter from both control plots.

the runoff water than either the dry or system plots (with 2 and 3 events where the beaker overflowed, respectively). This suggests that, even if a composite sample more representative of the total hydrograph was used, the comparison among the plots would have demonstrated similar results.

5.2.3 Grass Yields

Grass yields were taken from each of the three plots at the same time to compare the effects of renovated effluent on vegetation growth. Average yields were 29.89, 24.64, and 12.41 grams dry mass per square meter for the system, water and dry plots, respectively. Statistical comparison at the 0.05 probability level showed that the yields from the system plot were greater than yields from each control plot. The yield results, therefore, show no disadvantage of applying renovated wastewater and thus agree with many of the results previously presented.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The following are the conclusions and recommendations from this study.

6.1 CONCLUSIONS

Observations during this study of the operation of a partially saturated recirculating sand filter support the following conclusions about its renovation efficiency and the environmental impact of applying renovated septic tank effluent to a lawn surface.

6.1.1 Renovation Efficiency

A partially saturated recirculating sand filter may be used efficiently as an on-site domestic wastewater treatment system. Significant removals of nitrogen, as well as organics and bacteria, can be expected from a partially saturated recirculating filter. A recirculating sand filter may be used as an alternative treatment system to renovate domestic wastewater without the use of native soils in areas with inadequate soil conditions.

6.1.2 Environmental Impact

Application of renovated domestic wastewater onto a lawn can be expected to have no detrimental impact on either the off-site movement of pollutants by surface runoff or the growth of grass in the lawn. The risk of human exposure to coliform bacteria from a lawn being irrigated daily with renovated domestic wastewater is no greater during the summer than the risk of exposure to coliform bacteria from a conventional lawn. Results of the two exposure analysis procedures used in this study are inconclusive with respect to no increased exposure risks during other seasons.

6.2 RECOMMENDATIONS

Recommended design modifications described previously (Section 5.1.6) should be incorporated into laboratory and/or prototype systems so that their feasibility may be evaluated. Multiple systems should be operated in a manner that will permit identification of optimum operating criteria such as filter loading rate, recirculation ratio, as well as others. Results of such studies will contribute to the development of appropriate regulations and/or guidelines for the installation and operation of domestic wastewater renovation systems utilizing recirculating sand filters with lawn surface discharge.

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APPENDICES

APPENDIX A

RSF PROTOTYPE OBSERVED DATA

Table A.1 Observed Nitrogen Data Values for RSF Prototype.

WEEK	SAMPLE	NH3-N (MG/L)	NO3-NO2-N (MG/L)	TKN (MG/L)	TOTAL N (MG/L)
1	SYSTEM IN	27.61	0.03	32.63	32.66
2	SYSTEM IN	27.66	0.75	43.70	44.46
3	SYSTEM IN	21.85	0.05	29.57	29.62
4	SYSTEM IN	27.31	0.00	35.59	35.59
5	SYSTEM IN	21.10	0.20	29.71	29.91
6	SYSTEM IN	13.19	1.95	41.05	43.00
7	SYSTEM IN	21.96	0.75	27.87	28.61
8	SYSTEM IN	24.07	0.16	24.02	24.18
9	SYSTEM IN	13.18	0.14	18.87	19.01
10	SYSTEM IN	13.86	0.12	18.26	18.38
11	SYSTEM IN	26.37	0.00	31.06	31.06
12	SYSTEM IN	19.15	0.06	23.10	23.20
13	SYSTEM IN	17.41	0.00	20.33	20.33
14	SYSTEM IN	11.68	0.00	15.63	15.63
15	SYSTEM IN	13.42	0.00	21.34	21.34
16	SYSTEM IN	15.28	0.00	20.14	20.14
17	SYSTEM IN	24.14	0.00	29.91	29.91
18	SYSTEM IN	20.90	0.01	25.68	25.69
19	SYSTEM IN	20.81	0.00	30.77	30.77
20	SYSTEM IN	ERR	ERR	ERR	ERR
21	SYSTEM IN	18.26	0.05	35.60	35.65
22	SYSTEM IN	15.82	0.05	23.07	23.12
23	SYSTEM IN	20.93	0.46	29.13	29.60
24	SYSTEM IN	ERR	ERR	ERR	ERR
25	SYSTEM IN	34.54	0.00	41.94	41.94
26	SYSTEM IN	11.52	0.00	20.99	20.99
27	SYSTEM IN	14.28	0.00	22.22	22.22
28	SYSTEM IN	19.05	0.00	27.45	27.45
29	SYSTEM IN	25.01	0.00	34.60	34.60
30	SYSTEM IN	19.63	0.00	27.60	27.64
31	SYSTEM IN	13.03	0.00	23.66	23.66
32	SYSTEM IN	27.29	0.00	35.20	35.23
33	SYSTEM IN	25.82	0.00	36.15	36.15
34	SYSTEM IN	20.76	0.00	31.15	31.15
35	SYSTEM IN	27.72	0.00	38.50	38.49
36	SYSTEM IN	22.68	0.00	29.70	29.72
37	SYSTEM IN	31.12	0.10	41.00	41.10

Table A.1 (continued)

WEEK	SAMPLE	NH3-N (MG/L)	NO3-NO2-N (MG/L)	TKN (MG/L)	TOTAL N (MG/L)
1	SYSTEM OUT	6.42	0.20	9.47	9.68
2	SYSTEM OUT	12.06	1.41	23.65	25.06
3	SYSTEM OUT	6.93	0.67	10.75	11.42
4	SYSTEM OUT	14.90	0.78	20.05	20.83
5	SYSTEM OUT	20.49	0.20	23.76	23.95
6	SYSTEM OUT	ERR	ERR	ERR	ERR
7	SYSTEM OUT	14.64	0.87	18.50	19.37
8	SYSTEM OUT	2.62	0.77	4.18	4.94
9	SYSTEM OUT	6.79	0.70	8.59	9.29
10	SYSTEM OUT	7.47	0.35	8.77	9.11
11	SYSTEM OUT	5.80	0.84	7.16	8.00
12	SYSTEM OUT	2.09	0.40	2.70	3.11
13	SYSTEM OUT	2.15	0.34	4.40	4.73
14	SYSTEM OUT	2.72	0.07	4.64	4.71
15	SYSTEM OUT	2.53	0.10	3.92	4.01
16	SYSTEM OUT	4.44	0.07	6.18	6.24
17	SYSTEM OUT	2.04	0.09	3.42	3.51
18	SYSTEM OUT	3.04	0.06	3.92	3.98
19	SYSTEM OUT	ERR	ERR	ERR	ERR
20	SYSTEM OUT	ERR	ERR	ERR	ERR
21	SYSTEM OUT	0.79	0.14	15.92	6.94
22	SYSTEM OUT	1.52	0.72	2.83	3.55
23	SYSTEM OUT	1.37	0.18	5.39	5.57
24	SYSTEM OUT	ERR	ERR	ERR	ERR
25	SYSTEM OUT	1.68	1.27	3.07	4.34
26	SYSTEM OUT	1.73	1.19	4.10	5.29
27	SYSTEM OUT	0.74	2.70	3.10	5.80
28	SYSTEM OUT	1.38	4.50	6.16	10.66
29	SYSTEM OUT	1.36	4.09	4.04	8.14
30	SYSTEM OUT	2.13	1.51	5.80	7.27
31	SYSTEM OUT	1.37	1.70	2.15	3.86
32	SYSTEM OUT	2.01	0.79	6.85	7.68
33	SYSTEM OUT	4.15	0.00	6.10	6.08
34	SYSTEM OUT	3.24	0.00	7.35	7.35
35	SYSTEM OUT	4.24	0.08	9.60	9.70
36	SYSTEM OUT	3.18	1.08	4.65	5.70
37	SYSTEM OUT	6.80	0.14	8.00	8.14

Table A.1 (continued)

WEEK	SAMPLE	NH3-N (MG/L)	NO3-NO2-N (MG/L)	TKN (MG/L)	TOTAL N (MG/L)
1	FILTER IN	7.77	0.01	9.45	9.47
2	FILTER IN	12.69	0.36	22.15	22.11
3	FILTER IN	11.76	0.08	17.20	17.20
4	FILTER IN	16.55	0.00	21.10	21.09
5	FILTER IN	18.03	0.15	23.30	23.26
6	FILTER IN	20.19	0.07	20.50	20.53
7	FILTER IN	18.50	0.39	21.50	21.45
8	FILTER IN	9.92	0.33	11.00	10.97
9	FILTER IN	7.00	0.33	9.10	9.11
10	FILTER IN	7.80	0.12	8.30	9.27
11	FILTER IN	9.23	0.23	11.00	11.06
12	FILTER IN	5.71	0.02	6.20	5.19
13	FILTER IN	4.30	0.00	8.25	8.24
14	FILTER IN	3.13	0.00	5.15	5.19
15	FILTER IN	3.10	0.00	6.65	6.64
16	FILTER IN	4.86	0.04	6.75	6.71
17	FILTER IN	2.91	0.01	5.25	5.05
18	FILTER IN	3.50	0.02	6.00	5.99
19	FILTER IN	1.91	0.00	5.85	5.84
20	FILTER IN	0.00	0.73	2.10	2.12
21	FILTER IN	1.66	0.17	8.40	17.39
22	FILTER IN	2.23	0.54	4.35	4.35
23	FILTER IN	2.74	1.44	3.20	3.18
24	FILTER IN	N.D.	N.D.	N.D.	N.D.
25	FILTER IN	3.29	4.44	5.10	5.12
26	FILTER IN	3.20	0.83	6.10	6.14
27	FILTER IN	2.14	2.26	4.15	4.13
28	FILTER IN	1.88	4.82	5.05	5.04
29	FILTER IN	2.59	2.81	6.15	6.14
30	FILTER IN	2.39	1.67	5.30	5.30
31	FILTER IN	1.49	1.15	2.20	2.15
32	FILTER IN	3.17	0.75	7.65	7.65
33	FILTER IN	4.05	0.13	8.20	8.20
34	FILTER IN	3.65	0.20	8.75	8.75
35	FILTER IN	4.14	0.36	10.30	10.30
36	FILTER IN	3.98	1.31	5.35	6.64
37	FILTER IN	6.60	0.28	8.50	8.78

Table A.1 (continued)

WEEK	SAMPLE	NH3-N (MG/L)	NO3-NO2-N (MG/L)	TKN (MG/L)	TOTAL N (MG/L)
1	1 FILTER OUT	6.03	0.00	6.30	6.32
2	2 FILTER OUT	11.85	0.34	21.10	21.08
3	3 FILTER OUT	11.34	0.09	14.55	14.52
4	4 FILTER OUT	16.35	0.00	20.10	20.05
5	5 FILTER OUT	19.05	0.15	21.80	21.77
6	6 FILTER OUT	19.59	0.09	19.45	19.47
7	7 FILTER OUT	16.06	5.87	18.50	18.50
8	8 FILTER OUT	5.28	10.90	7.30	7.31
9	9 FILTER OUT	4.92	11.00	5.50	5.51
10	10 FILTER OUT	7.06	0.12	7.30	7.27
11	11 FILTER OUT	6.21	4.98	6.30	6.18
12	12 FILTER OUT	2.59	1.50	3.20	8.18
13	13 FILTER OUT	1.29	2.00	2.75	2.75
14	14 FILTER OUT	0.96	1.56	2.40	2.44
15	15 FILTER OUT	0.34	1.90	1.70	1.74
16	16 FILTER OUT	0.59	3.06	2.45	2.42
17	17 FILTER OUT	0.54	1.13	1.30	1.26
18	18 FILTER OUT	0.47	2.41	1.30	1.33
19	19 FILTER OUT	0.02	0.62	2.10	2.12
20	20 FILTER OUT	0.00	0.82	1.65	1.59
21	21 FILTER OUT	0.39	1.40	5.75	14.93
22	22 FILTER OUT	0.45	2.01	0.80	0.81
23	23 FILTER OUT	0.17	0.58	1.00	0.97
24	24 FILTER OUT	N.D.	N.D.	N.D.	N.D.
25	25 FILTER OUT	0.46	3.42	1.00	1.02
26	26 FILTER OUT	0.06	2.38	1.00	1.02
27	27 FILTER OUT	0.10	4.09	1.00	1.03
28	28 FILTER OUT	0.38	5.85	5.60	5.60
29	29 FILTER OUT	0.30	5.18	4.05	4.04
30	30 FILTER OUT	0.23	3.06	4.65	4.80
31	31 FILTER OUT	0.06	2.32	1.10	1.08
32	32 FILTER OUT	0.06	1.98	4.10	4.10
33	33 FILTER OUT	0.27	3.97	0.90	0.90
34	34 FILTER OUT	0.18	2.44	1.70	1.70
35	35 FILTER OUT	0.25	3.35	1.75	1.75
36	36 FILTER OUT	0.38	2.20	0.70	2.93
37	37 FILTER OUT	0.13	1.93	1.00	2.93

Table A.2 Observed Flow Rate and COD Values For RSF Prototype.

PROJECT WEEK	SAMPLE	FLOW RATE (L/WK)	COD (MG/L)
1	SYSTEM IN	2422.0	211.9
2	SYSTEM IN	3075.3	388.3
3	SYSTEM IN	2323.6	220.8
4	SYSTEM IN	2358.8	309.5
5	SYSTEM IN	2101.1	385.1
6	SYSTEM IN	1642.7	624.1
7	SYSTEM IN	1959.5	225.6
8	SYSTEM IN	2360.3	251.3
9	SYSTEM IN	1959.1	144.6
10	SYSTEM IN	2262.3	226.6
11	SYSTEM IN	2426.6	266.1
12	SYSTEM IN	2045.8	191.3
13	SYSTEM IN	2659.0	189.6
14	SYSTEM IN	2796.0	148.7
15	SYSTEM IN	2424.3	225.3
16	SYSTEM IN	2811.5	164.3
17	SYSTEM IN	2440.2	202.3
18	SYSTEM IN	2632.8	196.1
19	SYSTEM IN	2192.7	378.8
20	SYSTEM IN	272.1	N.S.
21	SYSTEM IN	1135.9	186.8
22	SYSTEM IN	1874.0	176.4
23	SYSTEM IN	2218.8	194.0
24	SYSTEM IN	2350.9	125.0
25	SYSTEM IN	2582.5	204.4
26	SYSTEM IN	2406.9	188.5
27	SYSTEM IN	1881.1	232.9
28	SYSTEM IN	1981.8	123.1
29	SYSTEM IN	1716.1	212.4
30	SYSTEM IN	2109.4	183.5
31	SYSTEM IN	1615.8	229.1
32	SYSTEM IN	1557.9	264.7
33	SYSTEM IN	2707.0	304.4
34	SYSTEM IN	2673.3	274.4
35	SYSTEM IN	2712.3	339.5
36	SYSTEM IN	2775.9	253.2
37	SYSTEM IN	2776.3	233.9

Table A.2 (continued)

PROJECT WEEK	SAMPLE	FLOW RATE (L/WK)	COD (MG/L)
1	SYSTEM OUT	3539.0	48.1
2	SYSTEM OUT	2985.6	72.1
3	SYSTEM OUT	2448.1	49.6
4	SYSTEM OUT	2348.6	64.8
5	SYSTEM OUT	2034.1	75.5
6	SYSTEM OUT	1740.0	N.S.
7	SYSTEM OUT	1803.6	109.6
8	SYSTEM OUT	2237.7	14.8
9	SYSTEM OUT	1787.7	21.0
10	SYSTEM OUT	2621.9	43.9
11	SYSTEM OUT	2381.9	32.1
12	SYSTEM OUT	2093.9	1.6
13	SYSTEM OUT	2563.2	17.3
14	SYSTEM OUT	2847.1	30.8
15	SYSTEM OUT	2355.8	25.4
16	SYSTEM OUT	2877.4	36.9
17	SYSTEM OUT	2473.1	13.8
18	SYSTEM OUT	2448.9	16.2
19	SYSTEM OUT	2351.6	N.S.
20	SYSTEM OUT	0.0	N.S.
21	SYSTEM OUT	1361.8	1.9
22	SYSTEM OUT	1898.2	0.0
23	SYSTEM OUT	2179.0	0.0
24	SYSTEM OUT	2414.1	2.3
25	SYSTEM OUT	2615.1	0.0
26	SYSTEM OUT	2355.0	10.5
27	SYSTEM OUT	1790.3	9.3
28	SYSTEM OUT	1967.8	0.0
29	SYSTEM OUT	1616.2	2.2
30	SYSTEM OUT	2165.0	8.0
31	SYSTEM OUT	1597.3	13.1
32	SYSTEM OUT	1476.2	23.7
33	SYSTEM OUT	2655.2	41.3
34	SYSTEM OUT	2599.5	16.4
35	SYSTEM OUT	2816.0	12.5
36	SYSTEM OUT	2523.8	10.3
37	SYSTEM OUT	2753.6	54

Table A.2 (continued)

PROJECT WEEK	SAMPLE	FLOW RATE (L/WK)	COD (MG/L)
1	FILTER IN	10504.5	50.6
2	FILTER IN	11218.0	84.6
3	FILTER IN	10299.4	42.2
4	FILTER IN	10196.0	63.6
5	FILTER IN	10161.2	71.8
6	FILTER IN	10302.4	36.8
7	FILTER IN	10301.6	70.8
8	FILTER IN	10440.5	57.9
9	FILTER IN	10640.8	29.8
10	FILTER IN	10307.7	18.1
11	FILTER IN	10459.5	34.7
12	FILTER IN	10520.4	25.9
13	FILTER IN	10475.7	37.4
14	FILTER IN	10484.8	18.3
15	FILTER IN	10394.0	24.2
16	FILTER IN	10317.2	41.8
17	FILTER IN	15147.9	33.9
18	FILTER IN	15258.8	18.7
19	FILTER IN	16003.7	19.8
20	FILTER IN	13936.4	8.7
21	FILTER IN	15602.5	5.0
22	FILTER IN	15296.3	0.0
23	FILTER IN	16211.9	0.0
24	FILTER IN	13521.2	6.0
25	FILTER IN	14233.1	0.0
26	FILTER IN	14311.1	27.9
27	FILTER IN	14957.2	22.0
28	FILTER IN	14120.3	0.0
29	FILTER IN	13881.9	13.0
30	FILTER IN	11260.0	3.0
31	FILTER IN	9581.7	11.9
32	FILTER IN	9087.0	33.5
33	FILTER IN	9224.8	46.9
34	FILTER IN	9296.0	33.9
35	FILTER IN	9403.1	18.2
36	FILTER IN	9827.8	9.5
37	FILTER IN	9319.4	70.7

Table A.2 (continued)

PROJECT WEEK	SAMPLE	FLOW RATE (L/WK)	COD (MG/L)
1	FILTER OUT	10504.5	19.4
2	FILTER OUT	11218.0	29.0
3	FILTER OUT	10299.4	18.6
4	FILTER OUT	10196.0	33.3
5	FILTER OUT	10161.2	41.6
6	FILTER OUT	10302.4	25.5
7	FILTER OUT	10301.6	32.3
8	FILTER OUT	10440.5	13.6
9	FILTER OUT	10640.8	18.4
10	FILTER OUT	10307.7	14.5
11	FILTER OUT	10459.5	9.5
12	FILTER OUT	10520.4	7.9
13	FILTER OUT	10475.7	6.0
14	FILTER OUT	10484.8	4.6
15	FILTER OUT	10394.0	1.7
16	FILTER OUT	10317.2	3.5
17	FILTER OUT	15147.9	0.0
18	FILTER OUT	15258.8	2.4
19	FILTER OUT	16003.7	0.0
20	FILTER OUT	13936.4	0.0
21	FILTER OUT	15602.5	3.1
22	FILTER OUT	15296.3	0.0
23	FILTER OUT	16211.9	0.0
24	FILTER OUT	13521.2	0.0
25	FILTER OUT	14233.1	0.0
26	FILTER OUT	14311.1	3.4
27	FILTER OUT	14957.2	4.2
28	FILTER OUT	14120.3	0.0
29	FILTER OUT	13881.9	0.0
30	FILTER OUT	11260.0	0.0
31	FILTER OUT	9581.7	0.0
32	FILTER OUT	9087.0	12.6
33	FILTER OUT	9224.8	8.0
34	FILTER OUT	9296.0	4.8
35	FILTER OUT	9403.1	13.7
36	FILTER OUT	9827.8	0
37	FILTER OUT	9319.4	31.1

Table A.3 Observed Coliform Data for RSF Prototype

PROJECT WEEK	SAMPLE	FECAL COL CFU'S/ML	FECAL COL CFU'S/ML LOG	TOTAL COL CFU'S/ML	TOTAL COL CFU'S/ML LOG
1	SYSTEM IN	1.10E+04	4.04	6.50E+04	4.81
2	SYSTEM IN	3.50E+02	2.54	4.00E+04	4.60
3	SYSTEM IN	1.50E+02	2.18	1.09E+04	4.04
4	SYSTEM IN	1.00E+03	3.00	6.55E+03	3.82
5	SYSTEM IN	2.23E+02	2.35	1.12E+04	4.05
6	SYSTEM IN	4.50E+02	2.65	2.50E+04	4.40
7	SYSTEM IN	3.50E+02	2.54	9.15E+03	3.96
8	SYSTEM IN	8.00E+02	2.90	1.21E+04	4.08
9	SYSTEM IN	4.00E+02	2.60	1.05E+04	4.02
10	SYSTEM IN	4.50E+02	2.65	1.50E+04	4.18
11	SYSTEM IN	3.00E+02	2.48	5.00E+04	4.70
12	SYSTEM IN	2.05E+03	3.31	7.00E+04	4.85
13	SYSTEM IN	1.50E+04	4.18	3.50E+04	4.54
14	SYSTEM IN	3.00E+02	2.48	1.50E+04	4.18
15	SYSTEM IN	1.30E+03	3.11	2.65E+03	3.42
16	SYSTEM IN	1.50E+02	2.18	5.50E+04	4.74
17	SYSTEM IN	4.00E+02	2.60	4.35E+03	3.64
18	SYSTEM IN	1.48E+02	2.17	5.30E+03	3.72
19	SYSTEM IN	1.50E+01	1.18	3.50E+02	2.54
20	SYSTEM IN	N.S.	N.S.	N.S.	N.S.
21	SYSTEM IN	2.65E+03	3.42	1.00E+04	4.00
22	SYSTEM IN	2.30E+03	3.36	2.50E+04	4.40
23	SYSTEM IN	6.50E+04	4.81	7.00E+04	4.85
24	SYSTEM IN	4.90E+03	3.69	5.10E+03	3.71
25	SYSTEM IN	2.32E+06	6.36	2.60E+06	6.41
26	SYSTEM IN	3.10E+07	7.49	7.40E+07	7.87
27	SYSTEM IN	4.65E+03	3.67	1.06E+04	4.02
28	SYSTEM IN	1.95E+03	3.29	3.05E+03	3.48
29	SYSTEM IN	1.20E+03	3.08	2.65E+03	3.42
30	SYSTEM IN	1.85E+03	3.27	3.20E+03	3.51
31	SYSTEM IN	3.65E+03	3.56	3.35E+03	3.53
32	SYSTEM IN	4.75E+03	3.68	8.50E+03	3.93
33	SYSTEM IN	1.85E+03	3.27	4.50E+03	3.65
34	SYSTEM IN	1.20E+03	3.08	4.00E+04	4.60
35	SYSTEM IN	1.95E+03	3.29	5.15E+03	3.71
36	SYSTEM IN	3.08E+02	2.49	1.25E+03	3.10
37	SYSTEM IN	2.00E+02	2.30	1.80E+03	3.26

Table A.3 (continued)

PROJECT WEEK	SAMPLE	FECAL COL CFU'S/ML	FECAL COL CFU'S/ML LOG	TOTAL COL CFU'S/ML	TOTAL COL CFU'S/ML LOG
1	SYSTEM OUT	2.65E+03	3.42	6.10E+03	3.79
2	SYSTEM OUT	2.00E+02	2.30	4.05E+03	3.61
3	SYSTEM OUT	1.50E+00	0.18	4.90E+01	1.69
4	SYSTEM OUT	1.65E+01	1.22	3.72E+02	2.57
5	SYSTEM OUT	1.20E+01	1.08	4.20E+03	3.62
6	SYSTEM OUT	N.S.	N.S.	N.S.	N.S.
7	SYSTEM OUT	7.20E+01	1.86	1.12E+04	4.05
8	SYSTEM OUT	1.50E+01	1.18	7.39E+02	2.87
9	SYSTEM OUT	1.50E+01	1.18	2.03E+02	2.31
10	SYSTEM OUT	6.50E+01	1.81	4.60E+02	2.66
11	SYSTEM OUT	1.00E+02	2.00	3.00E+02	2.48
12	SYSTEM OUT	1.98E+02	2.30	5.50E+02	2.74
13	SYSTEM OUT	3.50E+02	2.54	1.45E+03	3.16
14	SYSTEM OUT	1.50E+02	2.18	5.50E+02	2.74
15	SYSTEM OUT	1.00E+02	2.00	3.50E+02	2.54
16	SYSTEM OUT	7.00E+00	0.85	1.60E+03	3.20
17	SYSTEM OUT	3.00E+02	2.48	2.25E+03	3.35
18	SYSTEM OUT	1.10E+01	1.04	2.95E+03	3.47
19	SYSTEM OUT	N.S.	N.S.	N.S.	N.S.
20	SYSTEM OUT	N.S.	N.S.	N.S.	N.S.
21	SYSTEM OUT	1.50E+02	2.18	6.50E+02	2.81
22	SYSTEM OUT	2.00E+02	2.30	5.00E+02	2.70
23	SYSTEM OUT	1.00E+02	2.00	2.20E+03	3.34
24	SYSTEM OUT	2.50E+00	0.40	3.00E+00	0.48
25	SYSTEM OUT	9.50E+02	2.98	1.05E+04	4.02
26	SYSTEM OUT	3.50E+04	4.54	2.40E+05	5.38
27	SYSTEM OUT	1.72E+04	4.24	4.50E+04	4.65
28	SYSTEM OUT	5.00E-01	-0.30	4.50E+00	0.65
29	SYSTEM OUT	3.00E+00	0.48	2.40E+01	1.38
30	SYSTEM OUT	3.50E+02	2.54	6.50E+02	2.81
31	SYSTEM OUT	6.00E+02	2.78	4.50E+02	2.65
32	SYSTEM OUT	6.00E+02	2.78	5.00E+02	2.70
33	SYSTEM OUT	1.75E+03	3.24	2.00E+03	3.30
34	SYSTEM OUT	6.50E+02	2.81	8.00E+02	2.90
35	SYSTEM OUT	7.85E+01	1.89	1.09E+02	2.04
36	SYSTEM OUT	6.35E+01	1.80	6.15E+01	1.79
37	SYSTEM OUT	1.10E+01	1.04	4.35E+01	1.64

Table A.3 (continued)

PROJECT WEEK	SAMPLE	FECAL COL CFU'S/ML	FECAL COL CFU'S/ML LOG	TOTAL COL CFU'S/ML	TOTAL COL CFU'S/ML LOG
1	FILTER IN	7.85E+03	3.89	1.54E+04	4.19
2	FILTER IN	3.00E+02	2.48	5.00E+03	3.70
3	FILTER IN	9.00E+00	0.95	8.10E+01	1.91
4	FILTER IN	3.65E+01	1.56	6.50E+02	2.81
5	FILTER IN	5.50E+00	0.74	1.70E+03	3.23
6	FILTER IN	3.50E+00	0.54	3.00E+02	2.48
7	FILTER IN	1.75E+02	2.24	4.40E+03	3.64
8	FILTER IN	7.85E+01	1.89	1.80E+03	3.26
9	FILTER IN	2.40E+01	1.38	1.50E+03	3.18
10	FILTER IN	6.55E+01	1.82	6.00E+02	2.78
11	FILTER IN	1.00E+02	2.00	1.50E+03	3.18
12	FILTER IN	2.50E+02	2.40	2.80E+03	3.45
13	FILTER IN	8.00E+02	2.90	3.10E+03	3.49
14	FILTER IN	2.00E+02	2.30	1.30E+03	3.11
15	FILTER IN	5.00E+02	2.70	6.50E+02	2.81
16	FILTER IN	1.45E+01	1.16	3.05E+03	3.48
17	FILTER IN	3.00E+02	2.48	2.00E+03	3.30
18	FILTER IN	8.00E+00	0.90	1.55E+03	3.19
19	FILTER IN	2.15E+01	1.33	1.28E+02	2.11
20	FILTER IN	4.50E+00	0.65	2.00E+02	2.30
21	FILTER IN	1.50E+02	2.18	1.80E+03	3.26
22	FILTER IN	4.50E+02	2.65	9.00E+02	2.95
23	FILTER IN	2.00E+03	3.30	3.05E+03	3.48
24	FILTER IN	4.60E+01	1.66	5.30E+01	1.72
25	FILTER IN	5.56E+04	4.74	5.95E+04	4.77
26	FILTER IN	5.60E+05	5.75	1.42E+06	6.15
27	FILTER IN	1.48E+04	4.17	2.00E+04	4.30
28	FILTER IN	9.00E+00	0.95	1.10E+01	1.04
29	FILTER IN	3.05E+01	1.48	5.55E+01	1.74
30	FILTER IN	6.75E+01	1.83	6.90E+01	1.84
31	FILTER IN	1.09E+02	2.04	1.60E+02	2.20
32	FILTER IN	1.37E+02	2.14	2.00E+02	2.30
33	FILTER IN	1.20E+03	3.08	1.55E+03	3.19
34	FILTER IN	6.50E+02	2.81	9.00E+02	2.95
35	FILTER IN	6.45E+01	1.81	1.04E+02	2.02
36	FILTER IN	5.00E+01	1.70	1.50E+02	2.18
37	FILTER IN	2.95E+01	1.47	1.31E+02	2.12

Table A.3 (continued)

PROJECT WEEK	SAMPLE	FECAL COL CFU'S/ML	FECAL COL CFU'S/ML LOG	TOTAL COL CFU'S/ML	TOTAL COL CFU'S/ML LOG
1	FILTER OUT	2.60E+03	3.41	4.50E+03	3.65
2	FILTER OUT	6.20E+01	1.79	5.50E+02	2.74
3	FILTER OUT	6.50E+00	0.81	3.40E+01	1.53
4	FILTER OUT	9.00E+00	0.95	5.45E+01	1.74
5	FILTER OUT	6.50E+00	0.81	4.00E+02	2.60
6	FILTER OUT	4.50E+00	0.65	3.00E+02	2.48
7	FILTER OUT	1.00E+01	1.00	2.50E+02	2.40
8	FILTER OUT	3.50E+00	0.54	5.00E+01	1.70
9	FILTER OUT	5.00E+00	0.70	3.95E+01	1.60
10	FILTER OUT	4.50E+00	0.65	4.00E+01	1.60
11	FILTER OUT	1.00E+00	0.00	1.40E+01	1.15
12	FILTER OUT	1.05E+01	1.02	2.50E+01	1.40
13	FILTER OUT	6.00E+00	0.78	2.00E+01	1.30
14	FILTER OUT	1.00E+00	0.00	7.50E+00	0.88
15	FILTER OUT	3.50E+00	0.54	9.50E+00	0.98
16	FILTER OUT	0.00E+00	ERR	1.60E+01	1.20
17	FILTER OUT	1.00E+00	0.00	2.50E+00	0.10
18	FILTER OUT	0.00E+00	ERR	4.00E+00	0.60
19	FILTER OUT	1.20E+01	1.08	1.55E+01	1.19
20	FILTER OUT	0.00E+00	ERR	1.75E+01	1.24
21	FILTER OUT	3.00E+00	0.48	1.05E+01	1.02
22	FILTER OUT	5.50E+00	0.74	2.05E+01	1.31
23	FILTER OUT	4.00E+00	0.60	6.95E+01	1.84
24	FILTER OUT	1.50E+00	0.18	2.00E+00	0.10
25	FILTER OUT	3.10E+01	1.49	4.15E+01	1.62
26	FILTER OUT	3.66E+02	2.56	3.80E+02	2.58
27	FILTER OUT	6.50E+00	0.81	3.47E+02	2.54
28	FILTER OUT	1.50E+00	0.18	2.00E+00	0.30
29	FILTER OUT	5.00E-01	-0.30	2.50E+01	1.40
30	FILTER OUT	8.50E+00	0.93	9.00E+00	0.95
31	FILTER OUT	3.50E+00	0.54	5.00E+00	0.70
32	FILTER OUT	8.35E+01	1.92	1.50E+02	2.18
33	FILTER OUT	1.00E+00	0.00	2.00E+00	0.30
34	FILTER OUT	1.50E+00	0.18	1.20E+01	1.08
35	FILTER OUT	5.00E-01	-0.30	4.00E+01	1.60
36	FILTER OUT	1.50E+00	0.18	1.85E+01	1.27
37	FILTER OUT	0.00E+00	ERR	8.00E+00	0.91

APPENDIX B

RUNOFF DATA

Table B.1 Runoff Parameter Data Observations for Statistical Comparison

DAY	SAMPLE	VOLUME (LITER)	NH3-N (MG)	NO3-NO2-N (MG)	COD (MG)	FECAL COL (CFU's)	TOTAL COL (CFU's)	TOTAL N (MG)
41	DRY	0.000	0.00	0.00	0.00	0.00	0.00	0.00
56	DRY	0.040	0.04	0.22	1.87	0.00	0.00	0.37
57	DRY	0.000	0.00	0.00	0.00	0.00	0.00	0.00
72	DRY	18.192	22.80	14.16	9519.30	254.69	10605.94	64.46
92	DRY	0.179	0.58	0.14	19.82	0.00	0.00	2.51
93	DRY	0.000	0.00	0.00	0.00	0.00	0.00	0.00
141	DRY	0.195	0.62	0.11	12.25	0.00	0.00	2.39
142	DRY	0.550	1.31	0.18	4.77	0.00	0.55	9.74
150	DRY	0.334	0.21	0.09	2.08	0.00	167.00	0.42
164	DRY	1.475	2.19	0.64	57.68	6785.00	8997.50	3.23
195	DRY	0.125	0.13	0.05	0.00	25.00	437.50	0.40
208	DRY	0.300	0.17	0.10	0.52	2160.00	2610.00	1.54
249	DRY	0.000	0.00	0.00	0.00	0.00	0.00	0.00
256	DRY	2.800	3.02	1.99	74.20	0.00	0.00	7.59
258	DRY	0.350	32.24	0.30	34.37	98.70	175.00	35.30

Table B.1 (continued)

DAY	SAMPLE	VOLUME (LITER)	NH3-N (MG)	NO3-NO2-N (MG)	COD (MG)	FECAL COL (CFU's)	TOTAL COL (CFU's)	TOTAL N (MG)
41	SYSTEM	0.000	0.00	0.00	0.00	0.00	0.00	0.00
56	SYSTEM	0.040	0.04	0.26	8.08	0.00	0.00	0.53
57	SYSTEM	0.800	0.83	5.97	163.60	5.60	2960.00	11.40
72	SYSTEM	6.246	3.44	5.37	515.38	87.44	4909.36	28.74
92	SYSTEM	0.050	0.27	0.03	15.65	0.30	4.30	1.78
93	SYSTEM	0.020	0.05	0.01	0.67	0.00	0.00	0.14
141	SYSTEM	0.000	0.00	0.00	0.00	0.00	0.00	0.00
142	SYSTEM	0.000	0.00	0.00	0.00	0.00	0.00	0.00
150	SYSTEM	0.423	0.20	0.26	9.88	2157.30	11251.80	0.67
164	SYSTEM	4.684	8.29	1.57	68.16	468.40	1405.20	2.39
195	SYSTEM	0.030	0.04	0.02	0.00	117.00	324.00	0.14
208	SYSTEM	0.700	0.30	0.27	0.00	84.70	6300.00	1.53
249	SYSTEM	0.000	0.00	0.00	0.00	0.00	0.00	0.00
256	SYSTEM	2.050	0.68	2.52	66.83	0.00	0.00	4.57
258	SYSTEM	0.500	0.41	0.87	46.05	0.00	0.00	1.87

Table B.1 (continued)

DAY	SAMPLE	VOLUME (LITER)	NH3-N (MG)	NO3-NO2-N (MG)	COD (MG)	FECAL COL (CFU's)	TOTAL COL (CFU's)	TOTAL N (MG)
41	WATER	0.650	0.46	2.34	40.25	0.00	0.00	7.13
56	WATER	1.034	0.76	5.37	12.78	0.00	0.00	8.07
57	WATER	1.634	0.66	3.28	88.62	0.00	565.36	7.54
72	WATER	71.147	80.34	93.07	7124.89	0.00	0.00	498.04
92	WATER	3.174	1.63	0.04	145.26	355.49	2117.06	14.41
93	WATER	0.043	0.02	0.00	2.49	6.33	19.52	0.29
141	WATER	0.052	0.07	0.03	1.95	0.00	0.00	0.52
142	WATER	13.494	10.67	3.45	612.52	8096.40	275277.60	158.51
150	WATER	10.453	4.03	0.93	64.98	2090.60	363764.40	5.11
164	WATER	8.363	21.01	2.19	368.08	9199.30	29270.50	16.84
195	WATER	1.740	2.68	0.05	18.48	3480.00	10962.00	6.88
208	WATER	0.800	0.99	0.19	5.38	1280.00	1280.00	4.80
249	WATER	0.100	0.13	0.11	0.14	0.00	0.00	0.32
256	WATER	2.653	1.86	1.01	143.26	124.69	573.05	3.66
258	WATER	0.250	0.37	0.15	9.30	0.00	0.00	0.90

APPENDIX C

GRASS YIELD DATA

Table C.1 Grass Yield Data for Plot Harvest Comparison

DAY	SAMPLE	SAMPLE WEIGHT (GRAMS)	DRY MASS (%)	YIELD GRAM D.M. /SQ.METER
66	SYSTEM	1229	30.2	31.9
80	SYSTEM	683	22.9	14.9
91	SYSTEM	869	21.1	17.6
105	SYSTEM	902	29.2	25.2
121	SYSTEM	700	25.4	16.9
135	SYSTEM	930	25.7	22.8
148	SYSTEM	1317	18.4	23.2
161	SYSTEM	1467	16.5	23.2
170	SYSTEM	1637	17.8	27.9
186	SYSTEM	1998	17.9	34.2
211	SYSTEM	2322	26.7	59.2
234	SYSTEM	2654	24.2	61.4
66	WATER	173	38.1	6.3
80	WATER	299	31.4	8.9
91	WATER	201	27.1	5.2
105	WATER	257	32.9	8.1
121	WATER	168	32.2	5.2
135	WATER	405	28.8	11.2
148	WATER	776	20.4	15.2
161	WATER	510	19.9	9.7
170	WATER	1308	21.3	26.7
186	WATER	1552	23.2	34.5
211	WATER	4958	32.5	153.9
234	WATER	436	25.6	10.7
66	DRY	430	38.2	15.7
80	DRY	201	34.3	6.6
91	DRY	126	25.1	3.0
105	DRY	302	34.7	10.0
121	DRY	49	48.6	2.3
135	DRY	27	56.4	1.5
148	DRY	162	26.4	4.1
161	DRY	559	20.8	11.1
170	DRY	747	25.4	18.2
186	DRY	766	34.8	25.5
211	DRY	1063	35.2	35.8
234	DRY	557	28.4	15.1

APPENDIX D

COLIFORM BACTERIA RISK EXPOSURE DATA

Table D.1 Coliform Bacteria Data Values for Risk Exposure Statistical Evaluation

SAMPLE PLOT	TIME POINT	DRY MASS	FECAL COL CFU'S/SQ.IN	TOTAL COL CFU'S/SQ.IN	FECAL COL CFU'S/DRY GM	TOTAL COL CFU'S/DRY GM
SEPTIC SPRING	-5	23.05%	0.00E+00	1.98E+00	0.00E+00	2.39E+04
	0	20.38%	0.00E+00	6.17E+00	1.47E+03	4.07E+05
	5	23.06%	0.00E+00	5.56E+00	1.30E+04	3.30E+04
	10	17.84%	0.00E+00	8.64E+00	2.58E+04	3.25E+05
	15	21.60%	0.00E+00	1.74E+01	1.16E+04	1.44E+04
	20	25.08%	0.00E+00	1.26E+01	1.24E+04	3.31E+05
	25	19.86%	0.00E+00	1.14E+01	2.52E+04	4.28E+05
	30	20.96%	0.00E+00	6.17E+00	4.77E+03	9.49E+04
	45	20.41%	0.00E+00	1.23E-01	1.18E+04	1.20E+05
	60	20.79%	0.00E+00	5.68E+00	1.59E+04	2.21E+05
	75	19.43%	0.00E+00	4.44E+00	2.57E+03	2.68E+04
	90	23.38%	0.00E+00	4.20E+00	5.13E+03	4.83E+04
	105	21.49%	0.00E+00	1.48E+00	3.72E+03	2.37E+04
	120	24.44%	0.00E+00	4.20E+00	1.23E+03	4.66E+04
	135	22.73%	0.00E+00	3.83E+00	1.76E+03	1.10E+04
	150	26.26%	0.00E+00	3.46E+00	1.14E+03	7.62E+03
	165	26.63%	0.00E+00	1.23E-01	0.00E+00	4.43E+05
	180	25.73%	0.00E+00	3.70E+00	3.89E+02	2.80E+04
	195	23.63%	0.00E+00	1.60E+00	0.00E+00	1.52E+04
	210	30.51%	0.00E+00	0.00E+00	6.88E+03	3.41E+05
	225	23.54%	0.00E+00	6.17E-01	0.00E+00	5.01E+05
	240	23.66%	0.00E+00	3.70E-01	0.00E+00	3.85E+05

Table D.1 (continued)

SAMPLE PLOT	TIME POINT	DRY MASS	FECAL COL CFU'S/SQ.IN	TOTAL COL CFU'S/SQ.IN	FECAL COL CFU'S/DRY GM	TOTAL COL CFU'S/DRY GM
WATER	-5	20.87%	0.00E+00	0.00E+00	0.00E+00	2.54E+05
SPRING	0	20.30%	0.00E+00	1.23E-01	0.00E+00	4.04E+05
	5	20.16%	0.00E+00	2.47E-01	0.00E+00	1.04E+04
	10	21.57%	0.00E+00	0.00E+00	0.00E+00	1.35E+05
	15	21.01%	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	20	21.12%	0.00E+00	1.23E-01	0.00E+00	1.09E+04
	25	22.45%	0.00E+00	0.00E+00	0.00E+00	4.63E+05
	30	20.11%	0.00E+00	6.17E-01	0.00E+00	1.69E+05
	45	21.43%	0.00E+00	1.85E+00	0.00E+00	2.47E+05
	60	21.19%	0.00E+00	0.00E+00	0.00E+00	3.78E+03
	75	21.58%	0.00E+00	1.23E-01	0.00E+00	7.23E+04
	90	20.56%	0.00E+00	0.00E+00	0.00E+00	9.00E+05
	105	22.00%	0.00E+00	3.70E+00	0.00E+00	1.95E+04
	120	23.15%	0.00E+00	0.00E+00	0.00E+00	2.04E+05
	135	23.69%	0.00E+00	0.00E+00	0.00E+00	2.32E+05
	150	23.24%	0.00E+00	6.17E-01	3.87E+03	5.00E+05
	165	24.16%	0.00E+00	8.64E-01	0.00E+00	2.19E+04
	180	23.67%	0.00E+00	4.94E-01	0.00E+00	4.27E+05
	195	24.53%	0.00E+00	0.00E+00	0.00E+00	9.82E+04
	210	25.37%	0.00E+00	0.00E+00	0.00E+00	1.62E+04
	225	26.69%	0.00E+00	1.23E-01	0.00E+00	6.74E+03
	240	27.99%	0.00E+00	1.23E-01	0.00E+00	0.00E+00

Table D.1 (continued)

SAMPLE PLOT	TIME POINT	DRY MASS	FECAL COL CFU'S/SQ.IN	TOTAL COL CFU'S/SQ.IN	FECAL COL CFU'S/DRY GM	TOTAL COL CFU'S/DRY GM
DRY SPRING	-5	19.79%	0.00E+00	1.60E+00	0.00E+00	7.68E+04
	0	27.47%	0.00E+00	9.88E-01	0.00E+00	5.64E+05
	5	23.64%	0.00E+00	1.23E-01	0.00E+00	2.28E+05
	10	26.52%	0.00E+00	0.00E+00	0.00E+00	4.19E+05
	15	27.29%	0.00E+00	6.17E-01	3.66E+02	4.87E+05
	20	24.43%	0.00E+00	1.36E+00	0.00E+00	4.88E+05
	25	22.02%	0.00E+00	2.47E-01	0.00E+00	0.00E+00
	30	22.15%	0.00E+00	2.47E+00	0.00E+00	3.16E+03
	45	21.35%	0.00E+00	2.47E-01	0.00E+00	2.39E+05
	60	24.50%	0.00E+00	3.83E+00	0.00E+00	5.51E+05
	75	23.29%	0.00E+00	0.00E+00	0.00E+00	5.50E+05
	90	23.08%	0.00E+00	1.23E-01	0.00E+00	1.39E+05
	105	23.95%	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	120	23.48%	0.00E+00	1.11E+00	0.00E+00	2.13E+03
	135	25.84%	0.00E+00	0.00E+00	0.00E+00	7.00E+04
	150	23.18%	0.00E+00	9.26E+00	0.00E+00	1.91E+05
	165	26.18%	0.00E+00	0.00E+00	0.00E+00	4.86E+05
	180	27.29%	0.00E+00	1.48E+00	0.00E+00	2.27E+05
	195	28.97%	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	210	31.04%	0.00E+00	0.00E+00	0.00E+00	1.90E+05
	225	34.92%	0.00E+00	0.00E+00	0.00E+00	2.75E+05
	240	25.41%	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table D.1 (continued)

SAMPLE PLOT	TIME POINT	DRY MASS	FECAL COL CFU'S/SQ.IN	TOTAL COL CFU'S/SQ.IN	FECAL COL CFU'S/DRY GM	TOTAL COL CFU'S/DRY GM
SEPTIC	-5	15.18%	6.79E+00	4.51E+01	1.15E+07	1.32E+07
SUMMER	0	15.42%	1.11E+01	3.52E+01	1.10E+06	4.86E+06
	5	14.18%	5.68E+01	3.95E+01	1.27E+06	3.88E+06
	10	24.82%	4.07E+00	3.40E+01	2.82E+05	5.24E+06
	15	14.58%	4.94E+00	3.09E+01	2.06E+06	1.34E+07
	20	16.95%	7.28E+00	2.72E+01	8.85E+05	1.45E+07
	25	13.68%	4.94E-01	1.91E+01	2.78E+04	1.83E+06
	30	14.99%	2.10E+01	2.04E+01	2.00E+05	1.00E+07
	35	13.13%	8.64E+00	2.96E+01	9.90E+05	3.81E+06
	40	19.74%	3.70E+00	2.78E+01	2.03E+05	1.27E+06
	45	21.02%	1.30E+01	1.36E+01	7.14E+05	1.19E+07
	50	15.64%	1.98E+01	2.84E+01	8.31E+05	2.24E+06
	55	19.38%	1.17E+01	2.59E+01	5.16E+04	5.68E+06
	60	16.97%	4.94E+00	3.21E+01	5.89E+05	1.33E+07
	75	14.92%	6.17E-01	2.72E+01	1.21E+06	5.23E+06
	90	12.79%	5.00E+01	3.77E+01	1.72E+06	2.97E+06
	105	15.26%	3.89E+01	1.36E+01	5.90E+05	2.62E+06
	120	16.94%	2.59E+01	4.26E+01	1.71E+06	6.79E+06
	135	15.13%	3.95E+01	2.59E+01	6.61E+04	1.65E+06
	150	12.86%	3.70E+01	1.98E+01	4.51E+06	1.07E+07
	165	15.09%	3.52E+01	3.33E+01	8.61E+05	7.49E+06
	180	11.83%	4.94E+00	1.98E+01	1.69E+05	3.21E+06
	210	15.09%	2.84E+01	4.20E+01	3.31E+05	2.58E+07
	240	16.03%	1.33E+01	2.41E+01	6.24E+05	2.00E+07
	270	23.00%	2.47E+01	2.35E+01	3.91E+05	1.00E+07
	300	15.92%	7.41E-01	1.73E+01	1.88E+05	9.42E+06

Table D.1 (continued)

SAMPLE PLOT	TIME POINT	DRY MASS	FECAL COL CFU'S/SQ.IN	TOTAL COL CFU'S/SQ.IN	FECAL COL CFU'S/DRY GM	TOTAL COL CFU'S/DRY GM
WATER	-5	17.51%	4.20E+01	3.15E+01	5.03E+06	2.80E+06
SUMMER	0	16.88%	2.72E+00	2.47E+01	7.11E+05	1.78E+07
	5	17.01%	9.88E-01	2.35E+01	1.12E+06	2.59E+07
	10	18.90%	4.20E+00	2.41E+01	1.27E+06	2.22E+07
	15	19.91%	0.00E+00	1.85E+01	4.52E+05	1.66E+07
	20	16.79%	1.36E+01	1.05E+01	1.49E+06	1.97E+07
	25	15.56%	1.30E+01	1.85E+01	6.43E+04	5.14E+07
	30	20.49%	2.96E+00	1.85E+01	3.42E+05	1.95E+07
	35	24.24%	2.04E+01	1.91E+01	1.24E+05	8.25E+06
	40	21.63%	2.47E+01	1.30E+01	1.11E+05	3.70E+06
	45	21.32%	1.11E+01	2.28E+01	4.69E+04	9.38E+06
	50	15.18%	4.32E+00	2.10E+01	5.27E+05	9.88E+06
	55	17.55%	1.58E+01	6.17E+00	1.03E+06	2.68E+07
	60	17.72%	1.23E+00	1.17E+01	2.26E+05	2.82E+07
	75	18.30%	6.79E+00	9.26E+00	1.09E+05	8.20E+06
	90	15.54%	1.85E+00	5.31E+00	5.15E+05	3.73E+07
	105	17.66%	1.23E+00	1.17E+01	1.70E+05	4.53E+07
	120	21.69%	0.00E+00	1.67E+01	6.92E+05	1.20E+07
	135	15.70%	6.17E+00	2.04E+01	8.47E+06	3.31E+07
	150	17.34%	3.09E+00	1.48E+01	2.02E+06	5.77E+06
	165	22.23%	1.23E+01	1.23E+01	2.25E+05	1.12E+07
	180	18.55%	1.33E+01	1.60E+01	9.70E+05	2.43E+07
	210	20.65%	2.41E+01	1.73E+01	6.68E+06	1.40E+07
	240	25.12%	9.63E+00	2.35E+01	7.96E+05	1.99E+07
	270	24.70%	8.40E+00	2.65E+01	2.23E+06	1.17E+07
	300	27.04%	6.30E+00	8.64E+00	2.96E+05	3.33E+06

Table D.1 (continued)

SAMPLE PLOT	TIME POINT	DRY MASS	FECAL COL CFU'S/SQ.IN	TOTAL COL CFU'S/SQ.IN	FECAL COL CFU'S/DRY GM	TOTAL COL CFU'S/DRY GM
DRY SUMMER	-5	21.51%	1.04E+01	3.83E+01	4.65E+04	3.35E+07
	0	20.29%	9.26E+00	1.36E+01	2.46E+03	4.93E+06
	5	18.83%	1.30E+01	6.17E+00	2.66E+05	2.92E+06
	10	24.40%	1.23E+01	1.23E+01	3.69E+05	4.10E+06
	15	22.12%	1.60E+00	1.54E+01	4.52E+04	4.07E+06
	20	18.78%	4.32E+00	2.90E+01	6.92E+05	4.26E+07
	25	17.86%	6.79E+00	4.26E+01	2.24E+05	1.40E+07
	30	16.96%	2.65E+01	3.33E+01	1.36E+06	8.84E+06
	35	24.13%	1.79E+01	3.46E+01	1.66E+05	2.28E+07
	40	22.91%	2.59E+00	5.74E+01	8.73E+04	3.49E+07
	45	16.64%	5.56E+00	1.23E+01	9.01E+05	2.40E+07
	50	31.00%	9.26E+00	3.46E+00	2.26E+05	1.61E+07
	55	22.51%	5.19E+00	5.25E+01	1.33E+05	5.78E+06
	60	19.08%	8.64E+00	1.36E+01	9.43E+03	2.41E+07
	75	25.21%	3.83E+01	2.35E+01	1.98E+06	1.19E+07
	90	17.88%	3.95E+01	4.81E+01	7.83E+05	1.79E+07
	105	20.05%	1.01E+01	5.31E+01	2.49E+06	1.75E+07
	120	19.18%	4.44E+01	3.52E+01	1.56E+05	5.21E+07
	135	22.42%	1.54E+01	3.52E+01	4.15E+06	1.83E+07
	150	22.54%	5.19E+01	7.28E+01	6.21E+06	1.33E+07
	165	19.71%	1.79E+01	2.78E+01	5.07E+04	3.04E+07
	180	23.43%	1.67E+01	3.09E+01	1.71E+05	1.15E+07
	210	22.90%	2.33E+01	2.65E+01	8.73E+04	4.80E+06
	240	24.10%	3.83E+00	9.88E-01	4.15E+04	4.15E+06
	270	30.70%	1.73E+00	2.96E+00	1.27E+06	8.14E+05
	300	26.46%	1.48E+00	1.48E+00	1.81E+07	1.13E+06

Table D.1 (continued)

SAMPLE PLOT	TIME POINT	DRY MASS	FECAL COL CFU'S/SQ.IN	TOTAL COL CFU'S/SQ.IN	FECAL COL CFU'S/DRY GM	TOTAL COL CFU'S/DRY GM
SEPTIC	-5	37.69%	2.47E-01	2.47E-01	1.06E+06	1.33E+06
FALL	0	18.57%	5.19E+00	4.51E+00	1.62E+07	2.15E+07
	5	21.28%	2.84E+00	5.37E+00	1.39E+08	3.60E+08
	10	22.18%	4.57E+00	7.72E+00	3.61E+06	3.07E+07
	15	20.55%	9.01E+00	1.10E+01	4.62E+07	1.35E+08
	20	19.60%	1.42E+00	7.84E+00	1.53E+06	1.39E+08
	25	19.62%	1.37E+01	1.05E+01	5.10E+05	5.56E+07
	30	19.06%	5.37E+00	2.62E+01	8.81E+07	1.68E+08
	35	19.81%	4.57E+00	3.64E+00	1.67E+07	5.35E+07
	40	19.90%	5.56E+00	1.79E+01	1.16E+07	2.01E+07
	45	18.74%	5.25E+00	1.14E+01	5.34E+06	1.49E+07
	50	19.63%	3.09E+00	1.28E+01	2.65E+07	2.48E+08
	55	20.25%	1.34E+01	3.67E+01	1.48E+06	5.93E+07
	60	21.10%	4.88E+00	1.15E+01	2.42E+07	2.70E+07
	75	21.41%	1.28E+01	5.74E+00	7.43E+07	1.37E+08
	90	21.84%	2.28E+00	3.70E+00	1.65E+07	2.15E+07
	105	19.96%	2.10E+00	7.96E+00	6.01E+06	5.51E+07
	120	23.36%	5.00E+00	3.33E+00	1.63E+07	3.55E+07
	135	22.30%	2.47E+00	8.70E+00	8.30E+05	2.42E+07
	150	19.81%	1.91E+00	1.81E+01	5.55E+06	2.27E+07
	165	20.64%	2.41E+00	6.73E+00	2.91E+06	1.07E+07
	180	22.47%	3.02E+00	3.77E+00	2.67E+06	4.45E+06
	210	21.68%	2.59E+00	5.80E+00	4.61E+05	3.94E+08
	240	21.45%	1.85E+00	7.10E+00	9.32E+05	2.42E+07
	270	24.46%	1.17E+00	7.47E+00	4.50E+06	5.76E+07
	300	23.85%	1.11E+00	1.01E+01	4.19E+05	2.31E+08

Table D.1 (continued)

SAMPLE PLOT	TIME POINT	DRY MASS	FECAL COL CFU'S/SQ.IN	TOTAL COL CFU'S/SQ.IN	FECAL COL CFU'S/DRY GM	TOTAL COL CFU'S/DRY GM
WATER FALL	-5	30.20%	6.17E-01	0.00E+00	5.79E+05	1.32E+06
	0	25.44%	3.70E-01	3.46E+00	7.86E+05	1.18E+06
	5	22.60%	2.16E+00	1.11E+00	8.85E+05	2.57E+06
	10	22.28%	2.96E+00	2.47E-01	1.03E+07	1.93E+08
	15	25.78%	2.78E+00	6.17E-02	1.16E+06	1.98E+08
	20	23.37%	2.28E+00	1.23E-01	5.13E+06	6.42E+06
	25	23.76%	7.47E+00	1.43E+01	1.85E+07	2.15E+08
	30	24.45%	1.05E+00	1.11E+00	5.32E+06	1.35E+08
	35	26.43%	1.60E+00	1.23E-01	3.18E+05	1.06E+06
	40	20.81%	1.98E+00	1.73E+00	3.03E+07	4.28E+07
	45	27.38%	9.88E-01	2.16E+00	8.22E+05	3.65E+06
	50	27.25%	5.56E-01	3.46E+00	7.34E+05	1.25E+07
	55	24.53%	3.33E+00	9.26E+00	5.30E+06	8.11E+07
	60	30.07%	1.85E-01	7.41E-01	2.10E+07	3.46E+07
	75	22.27%	1.73E+00	2.72E+00	2.25E+06	9.88E+06
	90	26.07%	2.47E-01	4.69E+00	2.69E+06	3.34E+07
	105	27.08%	4.32E-01	1.11E+00	9.23E+06	1.11E+07
	120	23.29%	2.04E+00	5.00E+00	1.07E+05	4.29E+06
	135	22.17%	3.70E-01	2.78E+00	1.35E+06	3.56E+07
	150	22.07%	8.02E-01	9.26E-01	6.80E+06	9.97E+07
	165	24.41%	2.84E+00	1.21E+01	6.15E+06	5.53E+07
	180	26.49%	2.22E+00	7.22E+00	3.40E+06	2.27E+08
	210	26.07%	4.51E+00	3.95E+00	2.30E+06	2.45E+08
	240	24.42%	6.23E+00	2.96E+00	2.05E+06	6.43E+07
	270	29.80%	1.60E+00	1.23E-01	2.72E+07	1.28E+08
	300	28.96%	1.23E-01	8.77E+00	1.04E+06	2.42E+06

Table D.1 (continued)

SAMPLE PLOT	TIME POINT	DRY MASS	FECAL COL CFU'S/SQ.IN	TOTAL COL CFU'S/SQ.IN	FECAL COL CFU'S/DRY GM	TOTAL COL CFU'S/DRY GM
DRY	-5	68.04%	0.00E+00	0.00E+00	1.47E+05	1.31E+08
FALL	0	37.99%	0.00E+00	1.05E+00	9.21E+04	7.90E+05
	5	33.77%	0.00E+00	6.17E-02	3.26E+05	5.92E+05
	10	52.04%	0.00E+00	5.68E+00	5.19E+05	5.00E+06
	15	35.37%	2.47E-01	4.26E+00	8.48E+04	1.13E+05
	20	31.40%	1.85E-01	1.23E-01	1.43E+05	3.73E+07
	25	38.25%	0.00E+00	1.17E+00	1.31E+06	1.05E+07
	30	42.48%	0.00E+00	1.42E+00	2.82E+04	2.02E+08
	35	42.24%	0.00E+00	3.27E+00	1.66E+06	4.73E+06
	40	44.14%	0.00E+00	2.90E+00	3.62E+05	8.16E+06
	45	29.91%	0.00E+00	1.60E+00	7.69E+05	3.01E+06
	50	30.74%	0.00E+00	4.32E+00	0.00E+00	0.00E+00
	55	39.24%	6.17E-01	7.16E+00	6.37E+04	2.55E+06
	60	39.08%	0.00E+00	0.00E+00	8.96E+04	1.02E+06
	75	33.12%	0.00E+00	3.83E+00	8.15E+06	2.39E+07
	90	39.02%	0.00E+00	3.89E+00	1.28E+06	7.30E+07
	105	32.75%	2.47E-01	3.70E-01	6.11E+04	3.36E+06
	120	42.81%	0.00E+00	0.00E+00	7.01E+05	2.24E+06
	135	44.11%	1.85E-01	2.53E+00	3.40E+04	1.13E+06
	150	36.29%	0.00E+00	2.59E+00	3.31E+06	2.76E+06
	165	40.07%	0.00E+00	3.02E+00	8.73E+04	4.99E+05
	180	35.13%	0.00E+00	4.94E-01	0.00E+00	2.85E+06
	210	37.24%	6.17E-02	1.98E+00	2.69E+05	2.69E+05
	240	36.64%	6.17E-02	9.88E-01	8.19E+05	8.46E+06
	270	34.71%	0.00E+00	0.00E+00	2.02E+05	4.70E+07
	300	35.32%	1.23E-01	4.14E+00	1.13E+06	3.09E+07

VITA

John Wesley Kleene was born in Henderson, North Carolina, September 26, 1963. He was educated in the Wythe County School System in Virginia, and was graduated from Fort Chiswell High School in 1981.

In the fall of 1981, the author enrolled at Virginia Polytechnic Institute and State University in Blacksburg, Virginia. He completed his Bachelor of Science in Agricultural Engineering in March of 1986. Upon graduation, he accepted a research assistantship with the Department of Agricultural Engineering at the University of Tennessee, Knoxville. In March of 1989 the author accepted a research fellowship to pursue his Doctorate Degree with the Department of Agricultural Engineering at Virginia Polytechnic Institute and State University. The author completed the requirements for the Master of Science Degree with a Major in Agricultural Engineering and a Minor in Environmental Engineering in May of 1989.

The author is a member of Tau Beta Pi National Engineering Honor Society, Phi Kappa Phi National Honor Society, and Gamma Sigma Delta Honor Society of Agriculture. He also holds memberships in the Order of the Engineer, American Society of Agricultural Engineers, and the Soil Conservation Society of America.