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STIMULATION OF BIOLOGICAL DENITRIFICATION IN COLUMNS REPRESENTING RECIRCULATING SAND FILTERS

By

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ABSTRACT

STIMULATION OF BIOLOGICAL DENITRIFICATION IN COLUMNS REPRESENTING RECIRCULATING SAND FILTERS

By

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Nitrate contamination of the groundwater has been attributed to onsite disposal of wastewater in high density areas. The study evaluated a model recirculating sand filter system that was modified to stimulate denitrification. Columns were constructed to represent sand filters. These incorporated a saturated zone at the bottom of the column. Carbon was added to the saturated zone of one set of columns. Effluent was collected over a two month period and analyzed for TKN, NH_3-N, and NO_3-N.

NO_3-N concentration in the treated system column effluent was significantly lower than in the control and 80 percent reduction in total nitrogen was achieved. Denitrification in the recirculation tanks was a factor in reducing nitrogen concentrations in both systems.

Approved by:

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

INTRODUCTION

Onsite wastewater treatment systems have played an important role in disposing of our nation's wastewaters. Although estimates vary and actual numbers are hard to confirm, approximately 25 percent of the nation's households, or 18,000,000 units are currently using some type of onsite system for treating and disposing of their wastewater (EPA, 1977). It is also likely that onsite systems will continue to be a major component in efforts to provide an environmentally sound and sanitarily safe means of handling home sewage. As the more concentrated urban areas are "sewered" with centralized treatment facilities, pressure mounts to reduce the potential for pollution in the less densely housed suburban and rural areas. In these areas collection systems become much more expensive on a per capita basis with the major expenses being the installation of the collection system. As a result effective onsite systems become economically more attractive.

The bulk of the onsite systems in use are the conventional septic tank-soil absorption system. Properly installed and maintained septic tank-soil absorption systems have proven very effective in treating wastewater. Essential to good performance from a treatment standpoint is maintaining two or more feet of unsaturated, reasonably permeable soil below the leachfield and periodic removal of septage from the septic tank. Use of conventional septic tank soil absorption systems is limited by high water tables or shallow soils over bedrock where there is an inadequate soil volume to completely treat septic tank effluent. Finer textured soils also are limiting. Low permeability in clay soils requires an excessively large drainfield area to accept the daily wasteflow from a typical household. The United States Soil Conservation Service has estimated that as much as 68 percent of the total land area in the United States is unsuitable for installation of conventional soil absorption systems due to these limiting factors (EPA 1980).

A number of innovative systems have been devised to make onsite treatment a feasible alternative to collector systems where conditions are unsuitable for conventional onsite systems. Among these are elevated mounds, aerobic lagoons, and various sand filter systems.

These systems, as well as the conventional soil absorption systems, have proven effective in removing pathogens, suspended solids, and BOD_5 from wastewater. They have been less effective in removing nutrients, most notably nitrate-nitrogen.

Phosphorous removal is not a great problem in a properly selected site and well designed system. However, when phosphorous is discharged near or in the water table it can travel great distances in the groundwater. When systems are installed in shallow soils near surface waters, phosphorus movement from leachfields to lakes or rivers can contribute to eutrophication and general degradation of water quality.

Nitrogen concentration in these systems is reduced primarily by conversion of ammonia and organic nitrogen to nitrate nitrogen which is then leached to the water table. In rural areas with low density housing this is not of much concern, since the contribution of nitrogen from isolated systems will have little impact on nitrogen concentrations in the groundwater. However, in higher density areas, dilution may not be sufficient as a treatment process, particularly if the same residences rely on groundwater for drinking supplies. The U.S. Department of Public Health has set an upper limit of 10 mg/l nitrate-nitrogen as safe for drinking water. Excessive concentrations can lead to metheglobinemia in infants. The potential for nitrate contamination of groundwater from onsite wastewater treatment systems is a problem that needs to be addressed in the design of new alternatives.

CHAPTER TWO

LITERATURE REVIEW

Intermittent Sand Filtration

Intermittent sand filtration has been defined as the "application of wastewater to a bed of granular material which is underdrained to collect and discharge the final effluent" (EPA, 1980). While these systems are not currently widely used in Michigan they have been used to some extent in other states of the Mid-west, particularly for treating wastewater from schools and commercial establishments.

Design specifications vary but the essential features of an intermittent sand filter system are: 1) primary treatment system, (usually a septic tank); 2) underdrained sand filter; 3) a dosing and distribution system; and 4) a means of disposing of the final effluent.

Intermittent sand filters have proven to produce a high quality effluent, dependent on the dosing rate, incoming effluent quality, and midea size. Generally, treatment improves with decreasing dosing and particle size.

A Wisconsin study (Otis, 1973) showed a 95 percent reduction in BOD_5 and 80 percent reduction in suspended solids when septic effluent from an elementary school was passed through a sand filter bed. The same study found that total and fecal coliform counts were reduced by over 99 percent, although levels were still in excess of whole body contact standards. Total nitrogen was reduced by about

25 percent and phosphorus by 75 percent. However, nitrate-nitrogen levels exceeded 32 mg/l.

Sauer *et al*. (1976) compared septic tanks and aerobic treatment units as pretreatment methods and evaluated their effects on effluent quality from intermittent sand filters. Filter dosing rates varied from 8 cm/day (2 gpd/ft^2) to 80 cm/day (20 gpd/ft^2). The filter was composed of 60 cm of sand over 30 cm of stone. At the higher dosing rate BOD_5 was reduced from 120 mg/l to 22-25 mg/l when preceded by septic tank treatment. At 20 cm/day (5 gpd/ft^2) BOD_5 was reduced to 9 mg/l. Suspended solids were reduced from 45 mg/l to approximately 20 mg/l and 7 mg/l at high and low rates respectively. Phosphorus was reduced 20 percent at both rates with very little nitrogen reduction. At high rates most of the nitrogen was as ammonia while nitrates made up virtually all the nitrogen at low rates.

A Canadian study (Brandes, 1979) showed essentially no nitrogen removal in 120 cm sand filters of various composition dosed at 4 cm/day (1 gpd/ft^2). Nearly complete nitrification occurred and nitrate-nitrogen concentrations of 20-30 mg/l resulted. The only exceptions were in coarse sand and silty sand. In both cases the reduction in nitrate-nitrogen was made up for by increases in the concentrations of ammonia-nitrogen. Satisfactory treatment for coliform, BOD_5 and suspended solids occurred in all filters except in the coarse sand filter.

The principle disadvantage of the intermittent sand filter is the need for periodic maintenance of the sand surface and odor. Removal of the upper few inches of sand is required to preserve the original infiltration capacity and aeration. Open sand filters are easy to maintain but the offensive odors associated with septic tank effluent make them impractical where they cannot be isolated. Buried sand filters overcome some of the odor problems, but are more complicated to construct, are subject to inadequate aeration, and are more difficult to service.

Recirculating Sand Filter

In an effort to provide a filtration system that would eliminate the odor problem of the open type filters, two engineers with the Illinois Department of Public Health developed the recirculating sand filter (Hines and Favreau, 1974). Figure 1 is a diagram of the major components of the system. In the recirculating sand filter the filter dosing rate is from three to five times the daily waste flow. Filtered effluent is returned to the dosing chamber (recirculation tank) where it mixes with the incoming septic tank effluent. A ball and tee float valve arrangement in the return line from the filter diverts filtered effluent to a drainfield when the recirculation tank is full. In a well operating system odors are only detectable in the immediate vicinity of the filter as it is being dosed.

Maintenance is similar to that required with intermittent filter systems, consisting mainly of periodic scraping of the sand surface. One system installed at Kirtland Community College in the Northern Lower Peninsula of Michigan has operated for five years with service to the filter about every two years. A backup pump should be available in case the primary unit fails.

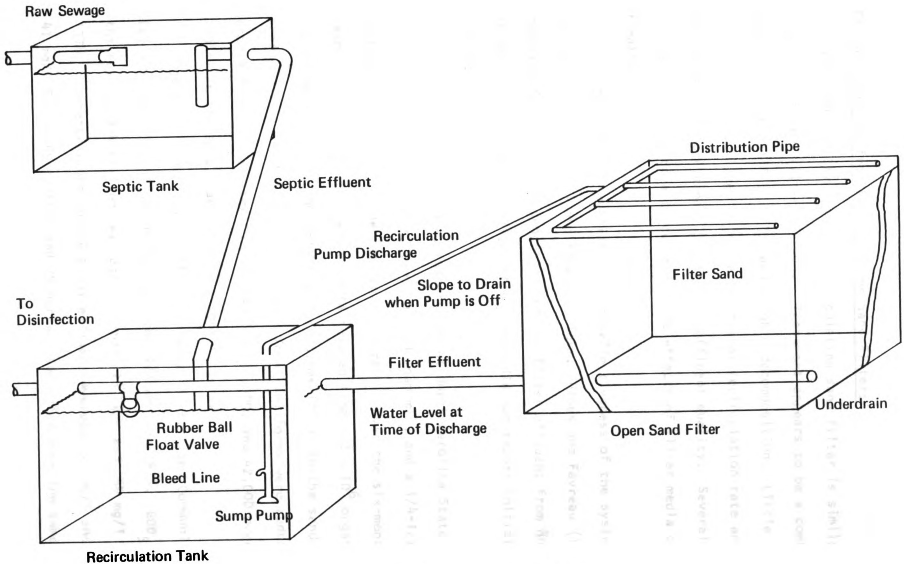

Figure 1. Recirculating Sand Filter

Effluent Quality from Recirculating Sand Filters

Effluent quality from the recirculating sand filter is similar to intermittent sand filter effluent. Treatment appears to be a combination of mechanical filtration and aerobic decomposition. Little work has been published on the effects that recirculation rate and dosing rate (filter area) have on effluent quality. Several studies have been done to determine the effects of filter media on treatment.

Not much data is available on the effectiveness of the system in the removal of fecal and total coliform. Hines and Favreau (1974) reported fecal coliform concentrations in filter effluent from 800 to 36,000 organisms per 100 ml, although they did not report initial concentrations.

In an unpublished work, researchers at North Carolina State University compared "filter" sand, a sand loam mix, and a 1/4-1/2 inch rock mix at a three to one recirculation rate. Over the six-month sampling period fecal coliforms were reduced from 1.2×10^6 organisms/100 ml to 10,000, 25,000 and 22,000 organisms/100 ml in the sand, sand loam, and rock mix respectively. Total coliforms were reduced from 4.8×10^6 organism/100 ml to 40,000, 39,000, and 42,000 organism/100 ml in the sand, sand loam, and rock filters.

The recirculating sand filter installed at Kirtland Community College (KCC filter) was monitored from 1977 through 1978. BOD_5 of the septic tank effluent averaged 250 mg/l in 1977 and 190 mg/l in 1978. Concentrations in the final effluent averaged 28 mg/l and 41 mg/l for an 89 percent and 79 percent reduction over the same period. These levels are higher than those reported by Hines and Favreau (1974) (1-7 mg/1) but they may have applied a less concentrated wastewater.

An Illinois study (Ralph, 1977) showed 83.4 percent removal of COD in a field filter at a five to one recirculation rate. The same study looked at various media in laboratory filters. A reduction of 88.2 percent in COD was accomplished with pea stone while 93.5 percent of the COD was removed with a medium sand. No significant differences were found between media.

Phosphorus removal has been more variable. The North Carolina State study showed from 33 percent to 45 percent reduction in total phosphorus. Phosphorus levels were not reported in the Illinois study. Phosphorus was reduced 75 percent in the KCC filter, from 28.8 mg/l to 7.2 mg/l. Two reasons may account for this difference.

1. The KCC system used a calcerious sand in the filter. Precipitation of phosphates may account for much of the phosphorus removal. The nature of the materials at North Carolina State was not reported.
2. Septic tank phosphorus concentrations were much higher at Kirtland than North Carolina State; 28.8 mg/l as opposed to 6.8 mg/l.

Final levels were much closer to the same; 7.2 mg/l as opposed to 3.75 mg/l to 4.75 mg/l. It is also interesting to note that the lowest levels at North Carolina State occurred in the rock filter. If adsorption of phosphorus was the principle method of removal, one would expect to see the lower levels in the sand-loam filter where the increased particle surface area would enhance absorption.

All three studies showed nearly complete removal of kjeldahl and ammonia nitrogen. This was influenced mainly by media texture in the Illinois study. Kjeldahl nitrogen was reduced by approximately 75 percent in the pea stone filter and over 95 percent in the sand filters. Kjeldahl nitrogen was composed mainly of ammonia-nitrogen, so similar ammonia reductions would be expected.

Media did not effect the North Carolina State filters' performance in removing kjeldahl and ammonia. Concentrations of Kjeldahl-nitrogen and NH_3-N were less than 1 mg/l.

The KCC filter averaged 7 mg/l TKN and NH_3-N, down from 130 mg/l and 57 mg/l TKN and NH_3-N in the septic tank effluent. Apparently, no organic nitrogen passed through the filter.

Essentially all the TKN and NH_3-N reduction in the North Carolina State filters could be accounted for by nitrification. Nitrate-nitrogen levels averaged about 20 mg/l, or about 90 percent of the total nitrogen in the septic tank effluent. NO_3-N in the septic tank effluent made up less than 2 percent of the total N.

NO_3-N made up about 2 percent of the total N in the septic tank effluent in the Illinois study as well, but from 87 to 93 percent of the total N in the filter effluent. Total nitrogen was reduced from 48 mg/l to about 25 mg/l or about 50 percent.

Total nitrogen was reduced by 75 percent in the KCC filter. NO_3-N concentrations averaged 27.3 mg/l and composed about 80 percent of the total N in the filter effluent.

None of the systems studied met USDPH standards for NO_3-N in drinking water. Even though the Illinois pea stone filter discharged effluent low in NO_3-N, it can be argued that the high TKN levels constitute a threat of NO_3 contamination. Once the effluent is exposed to the aerobic environment of the soil around the leachfield or receiving water, the organic and NH_3-N will be rapidly nitrified to NO_3-N. Ideally, the system should reduce the total nitrogen concentration to less than 10 mg/l to eliminate the risk of groundwater contamination.

Nitrification-Denitrification Studies

One means of reducing nitrogen concentrations in effluent is to take advantage of the recirculating sand filter's ability to nitrify essentially all the nitrogen in the effluent. Under the right conditions nitrate can be reduced to nitrogen gas (N_2) in a process called denitrification. Under anaerobic conditions a group of bacteria, collectively called denitrifiers, utilize NO_3 as an electron acceptor and carbon as an energy source. N_2 is one of the by-products of the metabolic process. The reaction can be represented by the equation:

$$NO_3^- + \text{carbon source} \xrightarrow[\text{bacteria}]{\text{denitrifying}} N_2 + H_2O + CO_2 + \frac{\text{cellular}}{\text{material}}$$

A number of researchers have looked at the potential of the denitrification process and different carbon energy sources for reducing nitrogen levels in effluent. Dholakia (1970) studied denitrification in packed columns and suspended growth reactors at three temperatures and several methanol concentrations. Raw sewage was aerated for 24 hours to achieve complete nitrification. Retention time in the suspended growth reactor was 210 minutes while the packed column reactor had a retention time of approximately 15 minutes. Temperatures were set at 30° C, 20° C and 5° C. Methanol concentrations were based on NO_3-N levels.

In the packed column reactor 97 percent, 97 percent and 96 percent NO_3-N reduction was accomplished at 30° C, 20° C and 5° C respectively at a CH_3OH:NO_3-N ratio of 3:1. Increasing the ratio resulted in no further NO_3-N reductions. At ratios less than 2:1 decreasing temperatures resulted in less denitrification. At a ratio of 1:1 only 50 percent NO_3-N reduction was achieved at 5° C.

Less denitrification was achieved in the suspended growth reactor. With a CH_3H;NO_3-N ratio of 3;1 at 30° C, 96 percent NO_3-N reduction occurred, however, 91 percent was the maximum removal at 20° C and 5° C. Again, a plateau was evident at a ratio of 3:1 with no temperature effect or increased nitrogen removal at higher ratios. NO_3-N levels from both reactors at a 3:1 CH_3OH:NO_3-N ratio were typically less than 1 mg/l, and it was concluded that the packed column type reactor was more efficient due to the shorter retention time required.

Sikora and Keeney (1975) in a Wisconsin laboratory study introduced aerated septic tank effluent to a packed column reactor with CH_3OH:NO_3-N ratio of about 2:1. At a depth of 14 cm, equivalent to 1.8 hr retention NO_3-N levels were reduced from 42.4 mg/l to 0.4 mg/l. When approximately 200 mg/l NO_3-N was introduced with a corresponding increase in CH_3OH concentration nearly complete denitrification was accomplished in 4.2 hours.

Based on these results Sikora et al. (1978) constructed a field system utilizing a septic tank sand filter system as an effluent source. Methanol was mixed with the nitrified effluent at twice the stochiometric concentration required to denitrify NO_3-N at 40 mg/l. Initially the system was operated on a 24-hour retention time in the denitrification unit. After 10 months the retention time was reduced to 12 hours.

Effluent NO_3-N levels ranged from 9 mg/l to 56 mg/l with almost no NH_3-N or organic-N. At the 24-hour retention time up to 99 percent nitrate removal was demonstrated. The shorter retention time resulted in an average of 90 percent NO_3-N removal with final concentrations from 2.2 mg/l to 6.4 mg/l. Total nitrogen never exceeded the 10 mg/l standard.

They concluded that the system was adequate for removal of nitrogen from small waste flows. The EPA Design Manual (1980) gives design specifications for this system and a modification of the same system for use below a soil leachfield (Fig. 2). In the leachfield system total nitrogen levels of less than 1 mg/l were reported in the summer use and 5-10 mg/l during the winter.

The principle disadvantage of these systems is the need to monitor NO_3-N concentrations in order to maximize denitrification and the added expense and complication of the methanol dosing unit.

Laak (1981) developed a system that reduces maintenance. The system uses separate septic tanks for blackwater and greywater. The blackwater septic tank effluent is nitrified by sand filtration and mixed with the greywater septic tank effluent in a denitrification

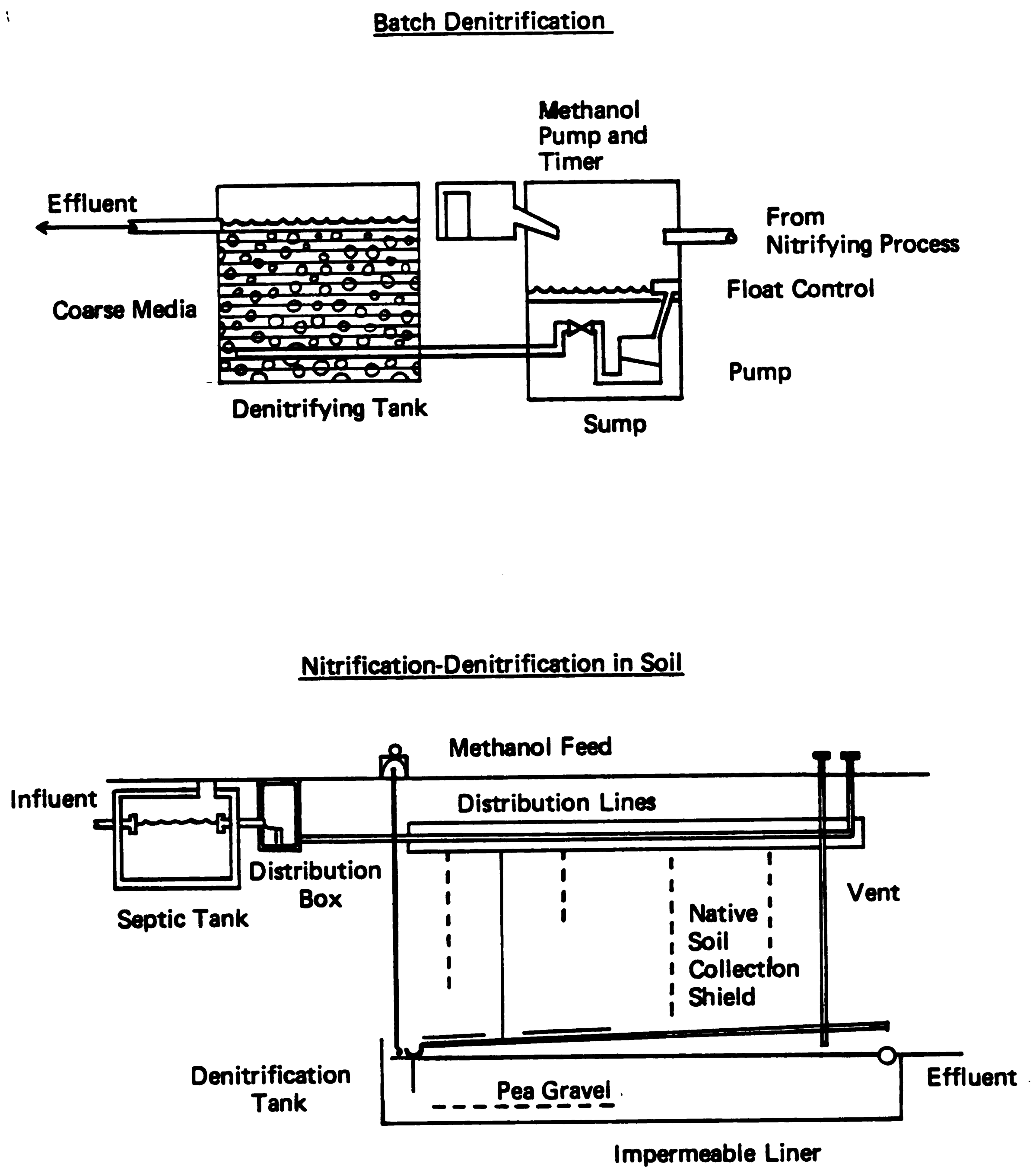

Figure 2. Onsite Denitrification Systems

unit similar to the one developed by Sikora. In a laboratory study nitrified effluent averaging 10 mg/l NO_3-N was reduced to 3 mg/l using greywater as a carbon source. NH_3-N, however, increased from 5 to 10 mg/l. In a full scale home system nitrified blackwater contained less than 65 mg/l NO_3-N. Denitrifying with greywater as a carbon source produced effluent with less than 5 mg/l NO_3-N and less than 10 mg/l TKN.

While this system is simpler in terms of maintenance, it still requires considerable expense to install the separate greywater system. Retrofitting in old homes may be less feasible than installation in new developments. What would be desirable would be to accomplish denitrification in the filter unit and reduce the number of components in the overall system. There is evidence to suggest that this is a feasible alternative.

Stewart (1979) applied untreated septic tank effluent to columns packed with loamy sand or a loamy sand-sand mix underlain with gravel or histic material to simulate treatment in mound systems. The columns were dosed twice daily at 1.65 cm/dose (.4 gpd/ft^2). Total length of the column was 180 cm with the lower 60 cm maintained in a saturated state. Approximately 90 percent nitrification was achieved 5 cm below the distribution system until a clogging zone formed and nitrification stopped. In columns containing no organic soil there was little reduction in NO_3-N levels during flow through the saturated zone. In columns with organic soil mixed in the saturated zone a 93 percent reduction in NO_3-N levels was observed after 42 days of operation. However, after 95 days only a 22 percent reduction occurred leading Stewart to conclude that all the available carbon had been exhausted sometime before 95 days.

In a similar study by Magdoff, Bouma and Keeney (1974) columns representing waste treatment mounds were constructed. The columns were dosed 4 times a day at 2 cm/dose (.5 gpd/ft^2). A gravel layer was placed at the bottom of the column directly under a layer of silt loam. This resulted in permanent saturation of the silt loam material. Nearly complete nitrification occurred after effluent passed through 30 cm of unsaturated sand. Some reduction in inorganic nitrogen levels occurred in the silt loam and was attributed to denitrification. Apparently the denitrification process was limited by the unavailability of carbon and short retention time in the saturated zone.

Enfield (1977) used digested municipal sludge to supply carbon for denitrification in columns packed with a gravelly loam soil. Secondary effluent application was regulated by measuring the Pt electrode potential at 6 cm and 30 cm with the desired effect to be establishment of an unsaturated zone over a saturated zone. The sludge was mixed in the upper 30 cm or banded at 30 cm. They found complete nitrification at 3 cm and 45 percent reduction in total nitrogen in the control column (no sludge) with about 90 percent of the nitrogen in the final effluent as NO_3-N. Both sludge amended columns resulted in more than 90 percent reduction in total nitrogen. In the columns with the sludge mixed in the upper 30 cm, nitrification and denitrification occurred simultaneously in the upper 30 cm. With the sludge banded, nitrification occurred above the band while denitrification occurred in or below the band. Dosage ranged from 29 cm/day (7 gpd/ft^2) in the control to approximately 24 cm/day in the mixed columns and 18 cm/day (4.4 gpd/ft^2) in the banded column.

Erickson, Ellis, and Tiedge (1974) developed the Barriered Landscape Water Renovation System (BLWRS) for treating agricultural wastewater. The system consists of a mound of sand over a barrier that creates a perched water table when the wastewater is applied to the mound. Supplemental carbon is added in the water table to enhance conditions for denitrification. Two BLWRS were constructed to treat swine and dairy wastes. The swine BLWRS was a fine sand capped with a sandy loam. The dairy BLWRS was a loamy very fine sand under a very fine sandy loam. Wastewater was applied at 1.8 cm/day (.44 gpd/ft^2) and .88 cm/day (.216 gpd ft^2) on the swine and dairy BLWRS respectively. Corn and molasses were evaluated as energy sources with a control receiving no supplemental carbon.

A maximum nitrogen removal of 97 percent was accomplished using corn on the dairy BLWRS. The swine BLWRS reduced total nitrogen by 80 percent with corn. The authors felt that insufficient quantities of molasses were used to have a great impact on denitrification. BOD_5 levels in the effluent were much higher than the control indicating that 1) too much corn was being used, or 2) that the corn decomposed more rapidly than it could be utilized.

It is apparent that the potential to denitrify nitrified effluent exists. The effectiveness of the denitrification process appears to be governed by the carbon source, retention time, and temperature. One problem with utilizing the process is the need to provide sufficient carbon for denitrification without contributing to the BOD_5 in the effluent.

CHAPTER THREE

OBJECTIVES

The objective of this project was to look at the nitrogen reduction effect of incorporating a saturated zone containing a carbon source in the bottom of a recirculating sand filter.

The nitrification and denitrification processes were included within the filter rather than in separate units as was the case with most of the previously described systems. This would simplify the overall treatment system by reducing the number of system components and possibly reduce costs.

Corn was used as a source of carbon for two reasons: 1) A slowly decomposable carbon source would require less frequent maintenance than a methanol injection system, and 2) corn had been an effective carbon source in the Barriered Landscape Water Renovation Systems.

CHAPTER FOUR

EQUIPMENT AND PROCEDURE

Six columns were constructed in the laboratory to simulate sand filters. The columns were identical except that three received supplemental carbon to stimulate denitrification. One recirculation tank supplied the three treated columns and another recirculation tank supplied the control columns. A common source of septic tank effluent was used. Figure 3 shows the arrangement of the laboratory system.

Column Construction

The columns were constructed of 15.24 cm (6 in) pvc pipe cut to 1.8 meters (6 ft) lengths and capped on one end (Fig. 4). Underdrains were fitted about 10 cm (4 in) from the capped end of the column. These consisted of 1.27 cm (1/2 in) pvc that had been drilled at 1.27 cm (1/2 in) intervals with .48 cm (3/16 in) holes. (.24 cm holes clogged during preliminary work.) The drains were placed in the columns with the holes facing downward and one end extending outside the column 7.6 cm (3 in). The ends were fitted with 30 cm (12 in) risers so that a saturated zone would be maintained in the bottom of the column when wastewater was applied.

Approximately 15 cm (6 in) of pea stone was poured into the columns to cover the drains and provide good drainage. The columns were then filled to a depth of 1.5 m (5 ft) with a commercially available sand. Particle size analysis (Appendix B) showed that the

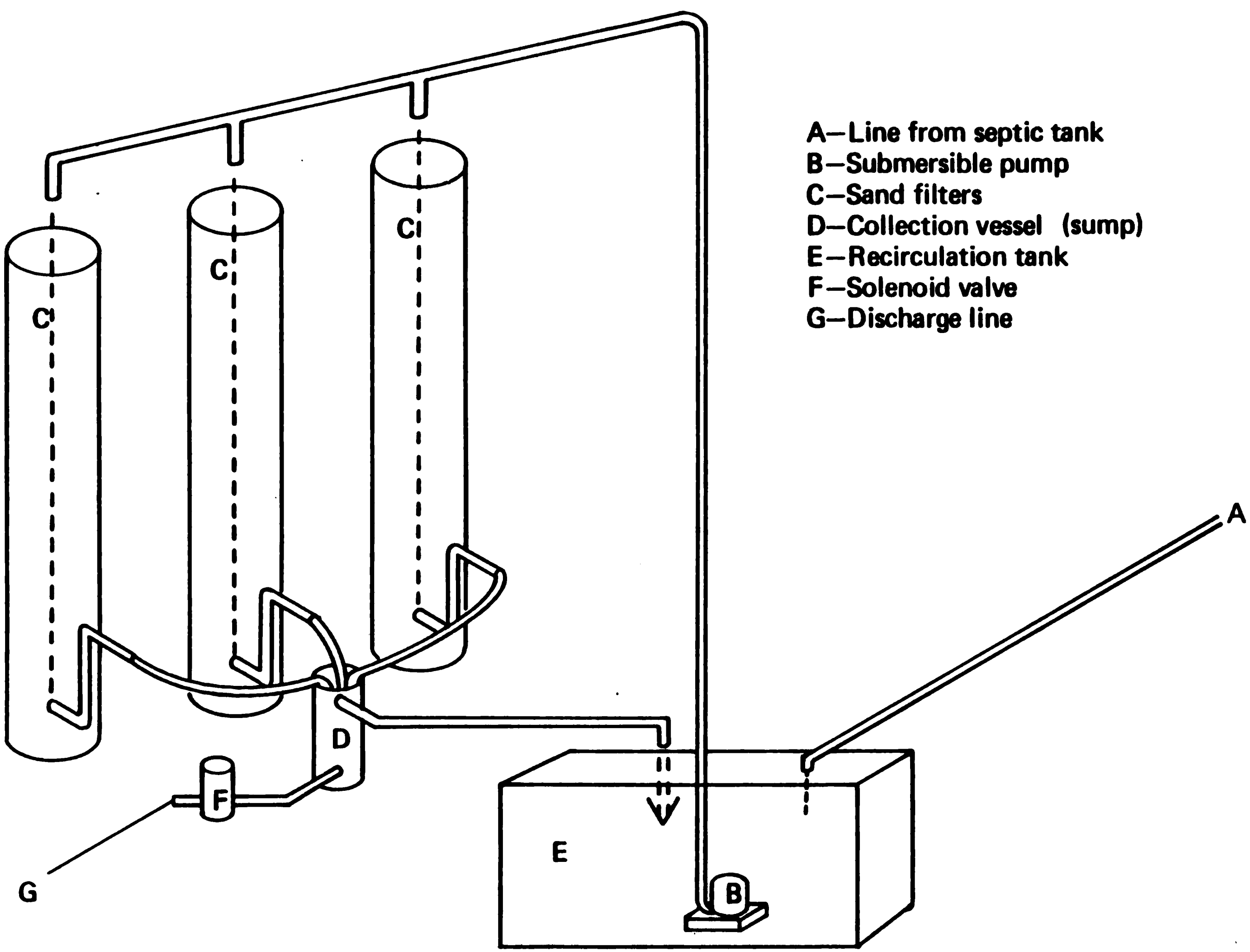

Figure 3. Laboratory Recirculating Sand Filter System

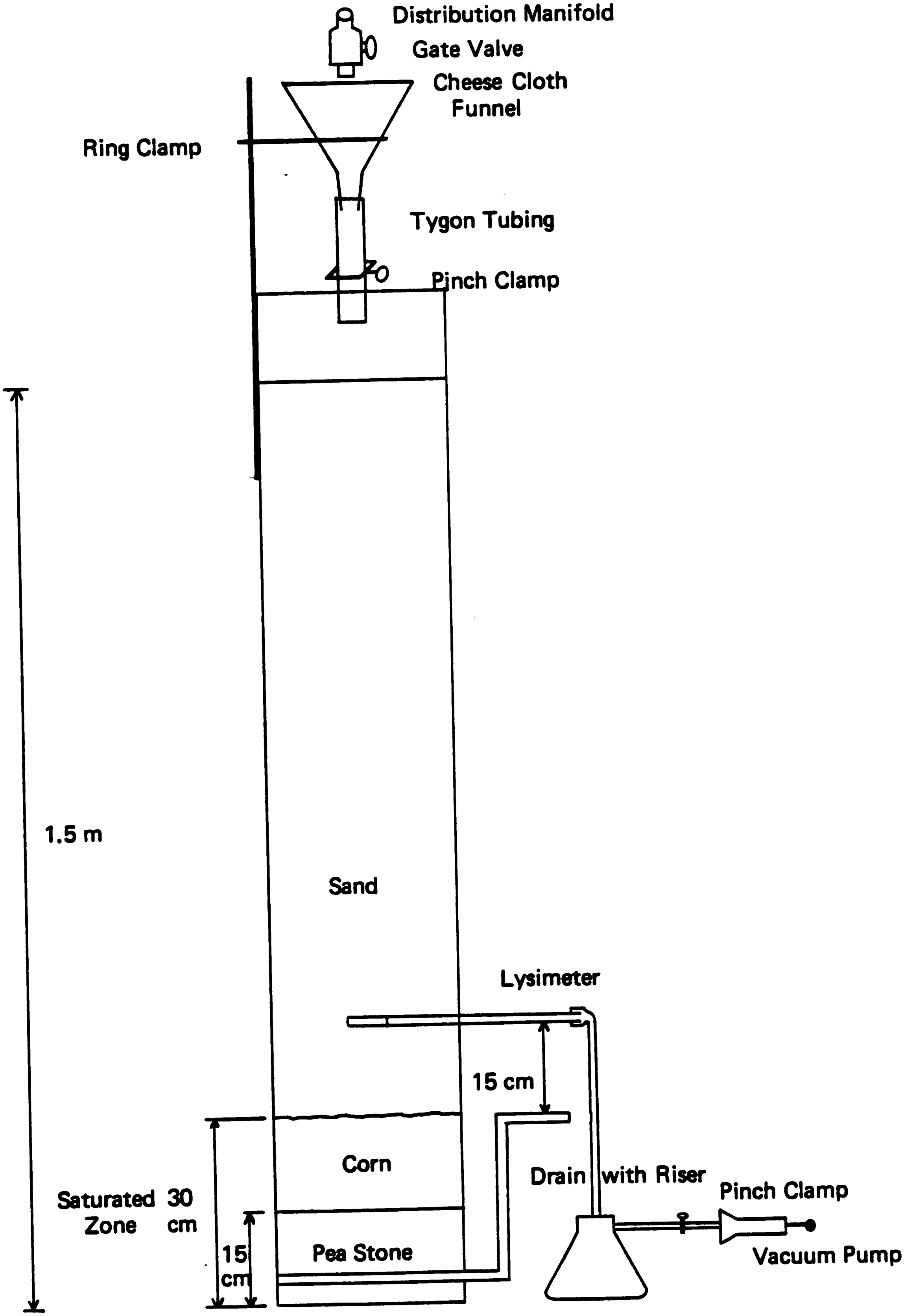

Figure 4. Laboratory Column

sand had an effective size of .27 mm and a uniformity of 3.07. The material was strongly effervescent with dilute HCl suggesting a calcarious nature and a potential to precipitate phosphorus.

In order to reduce the possibility of stratifying the sand when the columns were filled the following procedure was used. About 15 cm (6 in) of slightly moist sand was poured over the pea stone to hold it in place. The column was tipped on its side and the moist sand was pushed into the column. The column was tipped upright, lifted 5 cm (2 in) and dropped three times to settle the sand. Sand was then added or removed from each column so that each had a total depth of fill (sand and pea stone) of 1.5 meters (5 ft).

Approximately 50 grams of cracked corn was placed in the saturated zone of three of the columns to provide carbon for denitrification. The quantity was based on preliminary work where 200 grams of corn was used and high BOD_5 concentrations were observed in the effluent. The corn was placed in a band 30 cm (12 in) from the bottom of the columns.

After the columns were finished and filled with sand the sides of the pipe containers were perforated to improve oxygen diffusion into the columns by drilling 9.5 mm (3/8 in) holes through the pipe between the 10 cm (4 in) and 100 cm (40 in) depths of sand.

In order to facilitate sampling in the unsaturated zone of the column 1.27 cm (1/2 in) porous ceramic cup lysimeters were installed 15 cm (6 in) above the top of the drain riser.

Septic Tank

Septic tank effluent was obtained from a 2800 liter (750 gal) septic tank located in the Michigan State University Civil Engineering Kalamazoo Street Lab where the tests were run. Sewage was pumped six times a day from the East Lansing sewer main that ran just outside the lab to the septic tank at 935 liters/day (250 gpd) to provide three days retention in the septic tank. A manually operated self priming centrifugal pump transferred the septic tank effluent from the septic tank to the recirculation tanks. Initially, the pump ran on an automatic timer, but the intake frequently clogged with solid material from the septic tank. With the manual control, blockage was detected and corrected immediately. The pump was switched on long enough to refill the recirculation tanks to 60 liters (15 gal) once a day.

Recirculation Tank

Two 75 liter (20 gal) aquariums were used for recirculation tanks. These were covered with a sheet of plexiglass to more closely simulate a closed tank. Holes were drilled in the plexiglass to accommodate the influent line, effluent distribution line, drain return line and recirculation pump power cord. The effluent level maintained in the tank provided a maximum volume of 60 liters (15 gal).

Little Giant model 1-AA centrifugal submersible pumps were used for recirculation pumps. These were rated at 7.5 liters per minute (2 gpm) at 30.5 cm (1 ft) of head. They were placed on concrete blocks about 5 cm (2 in) above the tank bottom to avoid pumping accumulated sludge in the tanks. The pumps were controlled by a one hour repeat cycle timer and switched on once an hour.

Effluent was distributed to the columns through a manifold system constructed from 1.27 cm (1/2 in) pvc pipe (Fig. 3). Flow to each filter was regulated with gate valves. Even distribution to all columns was accomplished by adjusting each gate valve as needed. Once uniform flow was achieved the timer was set to deliver the required dose. Uniformity was checked periodically by turning on the recirculation pump and collecting the effluent from each manifold outlet. If the volume collected between outlets did not vary by more than fifteen percent, no changes were made. Otherwise, the valves were readjusted.

It was found that consistently uniform dosing to all columns was impossible to achieve at low flow rates (80 ml/min). When a rate of 1000 ml/min was applied, less variability in flow rate between columns occurred. However, when the dose was applied to the top of the columns at the high flow rate, the infiltration capacity of the sand was exceeded and flooding resulted. The earlier work indicated that flooding may have been a contributing factor in surface clogging. In order to reduce the application rate enough to prevent flooding, yet maintain reasonable uniformity, a small holding reservoir consisting of a 15 cm (6 in) funnel was placed between each manifold outlet and the corresponding column. The flow rate from the funnel was restricted by means of a pinch clamp fitted on a piece of tygon tubing attached to the end of the funnel. Flow was restricted so that the column received the dose over several minutes.

Initially, some solids were carried over from the recirculation tank and plugged the tubing at the pinch clamp. This was probably a result of the high solids content observed in the sewage used and low pressure at the pinch clamp. A piece of cheese cloth stretched over the funnel effectively filtered out the larger particles and eliminated the problem.

The recirculation rate was controlled with a sump arrangement in the return line from the filters. The sump was constructed from a plastic bottle with a bottom drain and an overflow line. The bottom drain was fitted with a normally closed solenoid valve. All three filters drained into the sump and the overflow line returned filtered effluent to the recirculation tank. The solenoid valve was controlled by a half hour recycle timer that opened the valve for one minute each half hour, discharging the contents of the sump. The fraction of effluent returned to the recirculation tank could be set by the volume of the sump. The sump volume also controlled the amount of effluent that was discharged, and consequently the septic tank effluent loading rate.

Dosing

The dosing rate was determined by the surface area of the columns and a standard dose of 12.2 cm/day (3 gpd/ft^2) based on septic tank effluent flow. Each column had a surface area of 182.4 cm^2 (.196 ft^2) so 2200 ml (.59 gal) of raw effluent was delivered to each column every day. The total flow of raw effluent for each system of three columns was 6.6 liters/day (1.7 gpd). The sump volume was fixed at 140 ml.

A recirculation rate of four to one was selected. Each column was to receive 8.8 liters (2.3 gal) of diluted effluent from the recirculation tank per day or 360 ml (.1 gal) per hour.

Some variability occurred between doses and the recirculation rate fluctuated between about four to one and 4.5 to one (360 ml to 400 ml/dose).

Sampling

The system was started up on August 19, 1981 and the first samples were collected on September 6, 1981. There were no specific intervals between sampling dates. Sampling continued through October 28, 1981.

The septic effluent, recirculation tank effluent and column effluent samples were collected in 500 ml bottles before the recirculation tanks were topped up except on the October 5 sampling date. The recirculation tank samples on October 5 were taken immediately after the daily dose of septic tank effluent had been added.

Samples were taken from the unsaturated zone in the columns by applying a vacuum to the lysimeters with a hand vacuum pump. The effluent was collected in a vacuum flask connected to the lysimeter with tygon tubing. It took twenty-four hours to draw a large enough sample for complete nitrogen analysis so these were started the day before the other samples were collected.

Analysis

The water samples were analyzed for ammonia nitrogen (NH_3-N), nitrate nitrogen (NO_3-N) and total kjeldahl nitrogen (TKN) concentrations the same day that they were collected.

Nitrate nitrogen concentrations were determined with an Orion model 93-07 nitrate ion electrode (Orion Research, 1977) and a Beckman 4500 digital pH meter. A stock 1000 mg/l NO_3-N solution was prepared by adding 721.8 g of anhydrous polassium nitrate to one liter of distilled water. From the stock solution, standard solutions of 100 mg/l, 10 mg/l and 1 mg/l NO_3-N were prepared. The nitrate electrode and a reference electrode were immersed in the standard solutions and the mV output recorded. The correlation between mV output and the log of the NO_3-N concentration was determined by linear regression. If the correlation equalled or exceeded .995 and the observed mV change was nearly 59 mV per log change in concentration, the analysis of the water samples proceeded.

Approximately 50 ml of each water sample was used for NO_3-N analysis. One ml of 2 N ammonium sulfate solution was added to the sample to keep the background ionic strength constant. The electrode was then immersed in the sample, the potential noted, and the NO_3-N concentration determined from the calibration curve generated by linear regression. All the samples and the standards were treated with .25 g of silver sulfate to avoid chloride interference.

Ammonia nitrogen concentration was determined with an HNU model ISE-10-10-00 ammonia electrode (HNU, 1978). The procedure was similar to that used for NO_3-N determination except that the standards were prepared from an ammonium chloride solution. The stock solution was prepared by dissolving 3.819 g of anhydrous ammonium chloride in one liter of distilled water. The probe was immersed in the standards prepared from the stock solution, one ml of 10 N sodium hydroxide solution added to convert ammonium to ammonia, and the potential noted. A calibration curve was generated as with the nitrate probe and the samples were analyzed.

Total kjeldahl nitrogen was determined as outlined in Standard Methods for the Examination of Water and Wastewater (1975) except that 3.5 g of copper sulfate was substituted for 2 g of mercuric oxide per liter in the digestion reagent (Repko, 1982). The digested sample was then analyzed by the same procedure as used for NH_3-N determination.

Total nitrogen was determined by adding the total kjeldahl nitrogen concentration and the nitrate nitrogen concentration.

The lower limit of detection with the nitrate probe of .14 mg/l NO_3-N and a linear response between 1 mg/l to 1000 mg/l was stated by the manufacturer (Orion, 1979). The lower limit of detection for NH_3-N with the HNU probe was claimed at less than .01 mg/l NH_3-N. The linear portion of the response curve to NH_3-N concentration was between .1 mg/l to 1400 mg/l (HNU, 1978).

CHAPTER FIVE

RESULTS AND DISCUSSION

General System Performance

Several problems were encountered related to the performance of the laboratory systems. The formation of a clogging mat that restricted infiltration in the control columns was observed after about twenty-five days of operation causing recirculation tank effluent to pond on the sand surface. The sand was stirred to break up the mat simulating normal filter maintenance. However, clogging continued to be a problem with the control columns.

After thirty days clogging was also observed in two of the treated columns. At this point both systems were turned off for twenty-four hours to allow the surfaces of the columns to dry out. The dried surfaces were stirred to break up the crust and the pumps were switched back on. This action appeared to restore the infiltration capacity. Sampling was suspended for three days after the systems were restarted.

At forty-five days two columns of each system were so severely clogged that effluent was over-flowing the column casing. The recirculation pumps were turned off and the ponded effluent was bailed out. Approximately 7.6 cm (3 in) of sand was removed from each column except from one column of the control system. It was black and anaerobic to a depth of about 14 cm (5.5 in). Sand was removed from it to the 15 cm (6 in) depth. Clean sand was added to each column to replace the sand that was removed. No more clogging was observed during the remaining thirty days of the sampling period, and the systems continued to run through the month of November with no evidence that clogging was occurring.

On October 1 (day 42) a storm knocked out the motor control transformer for the sewage pump supplying the septic tank. The pump was out for one week before the transformer could be replaced.

The time clock controlling the recirculation pumps was checked at the termination of the experiment and was found to be switching "on" for 30 seconds each hour instead of 15 seconds as had been originally set. Both recirculation pumps ran off this clock so uniformity of effluent application was not effected, but the recirculation rate was increased to eight to one. This also doubled the hydraulic loading rate on the columns and may have contributed to the clogging problems mentioned earlier. It did not, however, change the BOD_5 loading rate which was a function of the septic tank effluent loading rate.

Results of Sample Analysis

The results of the sample analysis are summarized in Table 1. Total nitrogen concentrations in the septic tank effluent averaged 38.0 mg/l and were reduced by 70 percent and 80 percent in the control and treated systems respectively. Total nitrogen concentrations averaged 10.9 mg/l and 7.6 mg/l in the drains of the control and treated columns respectively. There was little difference in total nitrogen concentrations from the lysimeter samples between treatments or between the lysimeter and the drain in the treated columns. The

Table 1. Average total kjeldahl, ammonia and nitrate nitrogen concentrations and 95 percent confidence limits.

	Ave. TKN	95% CL	Ave. NH_3N	95% CL	Ave. NO_3	95% CL
Septic tank	37.2	26.9-47.5	30.5	22.8-38.2	0.8	.3- 1.3
Control system						
Recirc. tank	11.3	5.6-17.0	6.4	4.7- 8.1	1.6	0.7- 2.5
Lysimeter	1.0	1.0- 1.6	0.7	0.6- 0.8	7.3	6.1- 8.5
Drain	.9	0.7- 1.2	0.5	0.3- 0.7	10.0	8.6-11.4
Treated system						
Recirc. tank	8.8	4.1-13.5	5.7	3.2- 8.2	1.2	0.5- 1.9
Lysimeter	1.1	0.8- 1.4	0.5	0.3- 0.7	6.1	5.1- 7.1
Drain	0.8	0.5- 1.1	0.2	0.1- 0.3	6.8	6.0- 7.6

average total nitrogen concentration in the drain samples from the control system was higher than in the lysimeter samples.

The average NH_3-N concentration in the septic tank effluent was 30.5 mg/l and represented about 80 percent of total nitrogen. NH_3-N concentrations were reduced to nearly zero in the drain samples from both systems. Little difference in NH_3-N concentrations was observed between the lysimeters and drains of either system or in the lysimeter samples between systems. In all cases concentrations were less than 1 mg/l. Essentially all the NH_3-N was nitrified or volatalized in the upper 100 cm of the columns.

Nitrate nitrogen made up approximately 90 percent of the total nitrogen in the drain samples from both the control and treated systems and less than one percent of the total nitrogen in the septic tank effluent. NO_3-N made up 12 percent of the total nitrogen in the recirculation tanks. The average NO_3-N concentration in the control column drains (10.0 mg/l) was 2.7 mg/l higher than the concentration in the lysimeter samples and accounted for the increase in total nitrogen. There was little difference in NO_3-N between the lysimeter and drain in the treated columns or between the control and treated column lysimeters.

There was a great fluctuation in total nitrogen concentration with time (Figs. 5 and 6); particularly in the septic tank effluent. The total nitrogen concentrations in the recirculation tanks was less variable and not much different than the total nitrogen concentrations in the lysimeters and drains. The peak at day 48 corresponds with the October 5 sampling date when the recirculation tank samples were collected after the recirculation tanks were dosed rather than before as was the case on all the other dates. On most sampling dates, total nitrogen concentrations in the control column drains were higher than in the lysimeter. Total nitrogen concentrations in the treated column lysimeter and drain were nearly equal on most sampling dates.

Nitrate nitrogen concentration variations with time are presented in Fig. 7 for the control system and Fig. 8 for the treated system. Nitrate-N levels were fairly stable in the septic tank effluent but appeared to increase in the recirculation tanks beginning around day 40. This may have been a result of the failing clock that controlled the recirculation pumps. As the recirculation rate increased a greater fraction of the tank volume would have been filtered effluent which contained relatively high concentrations of NO_3-N.

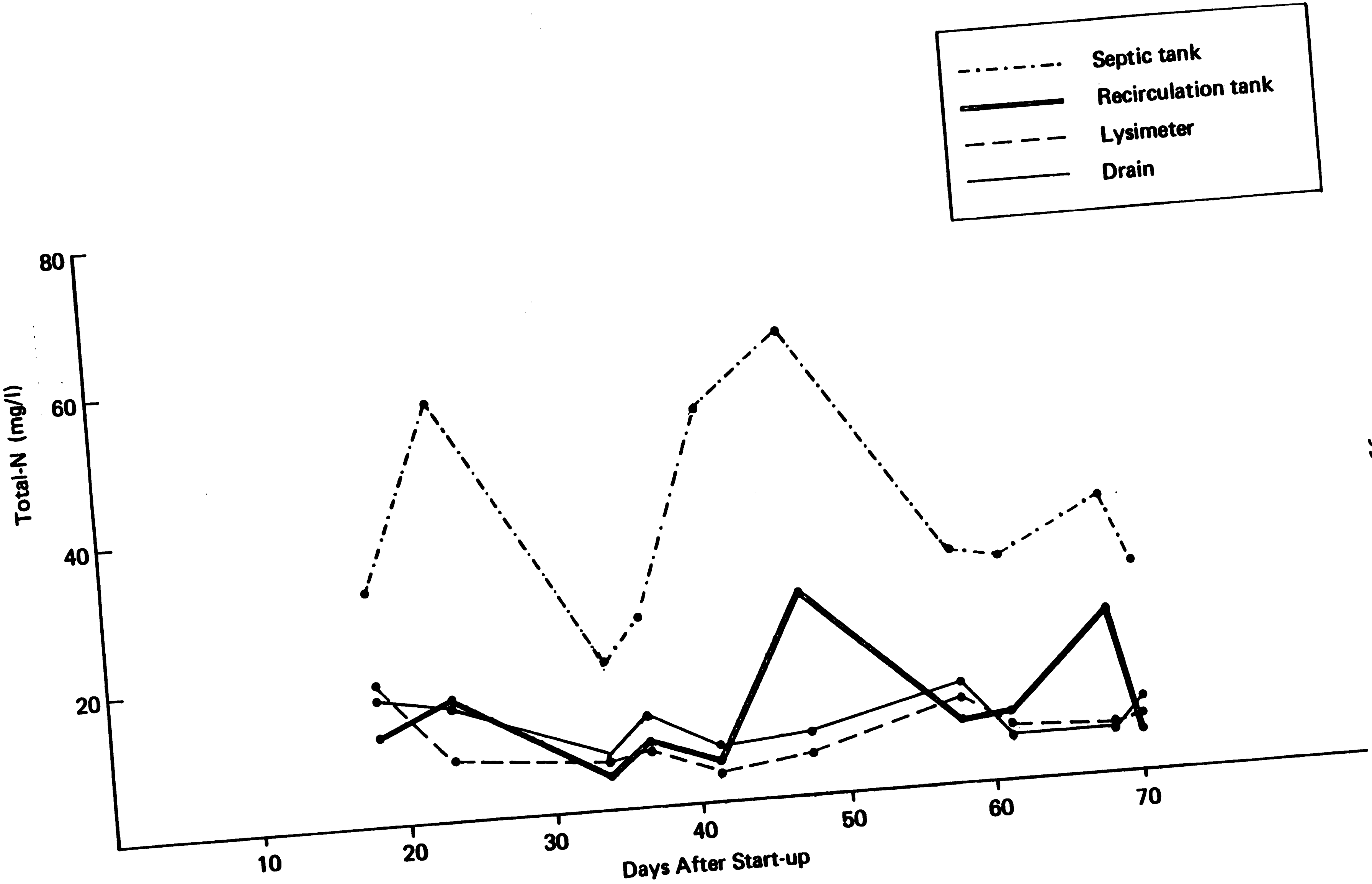

Figure 5. Total-N Control Columns

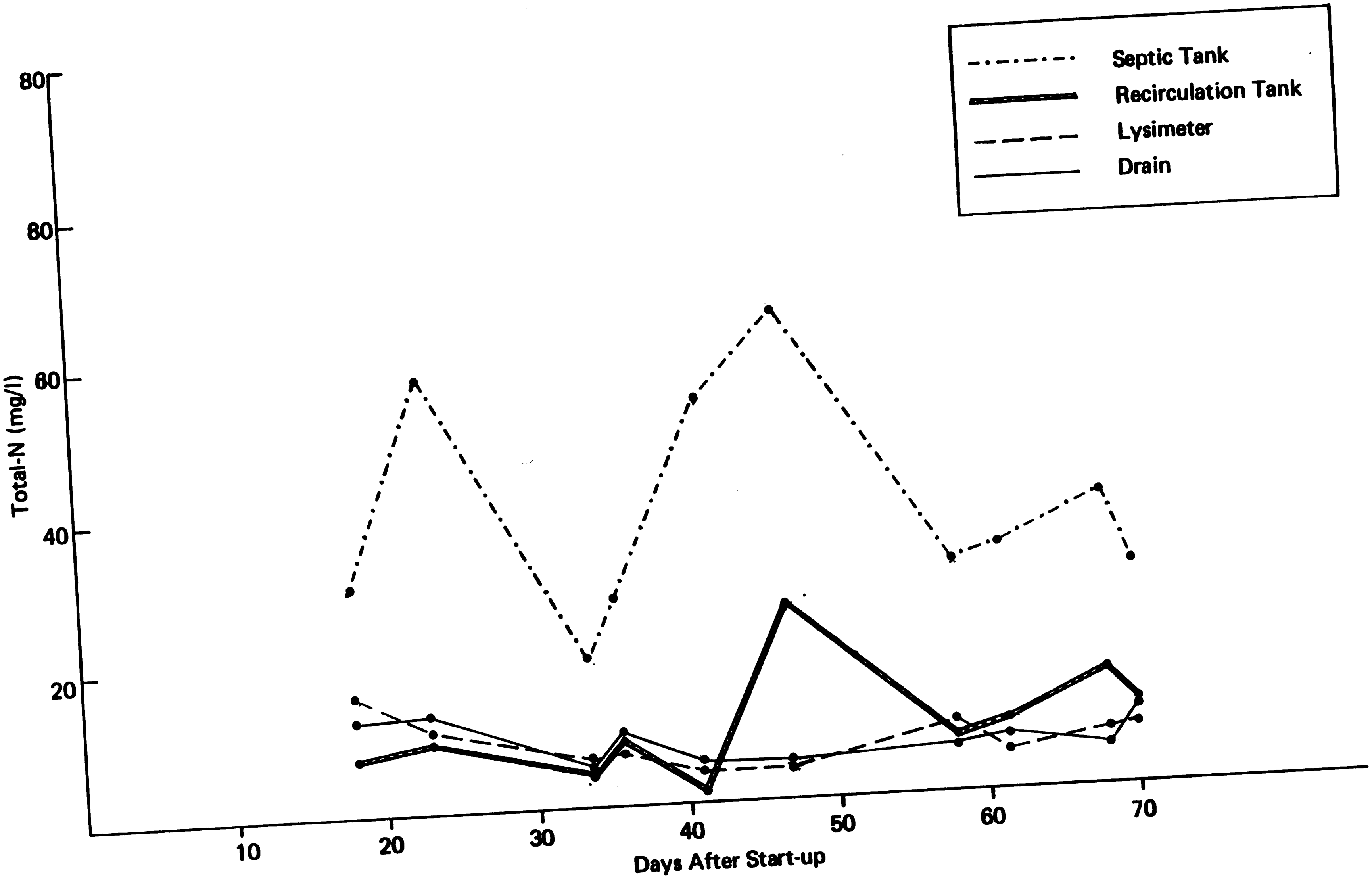

Figure 6. Total-N vs. Time Treated Columns

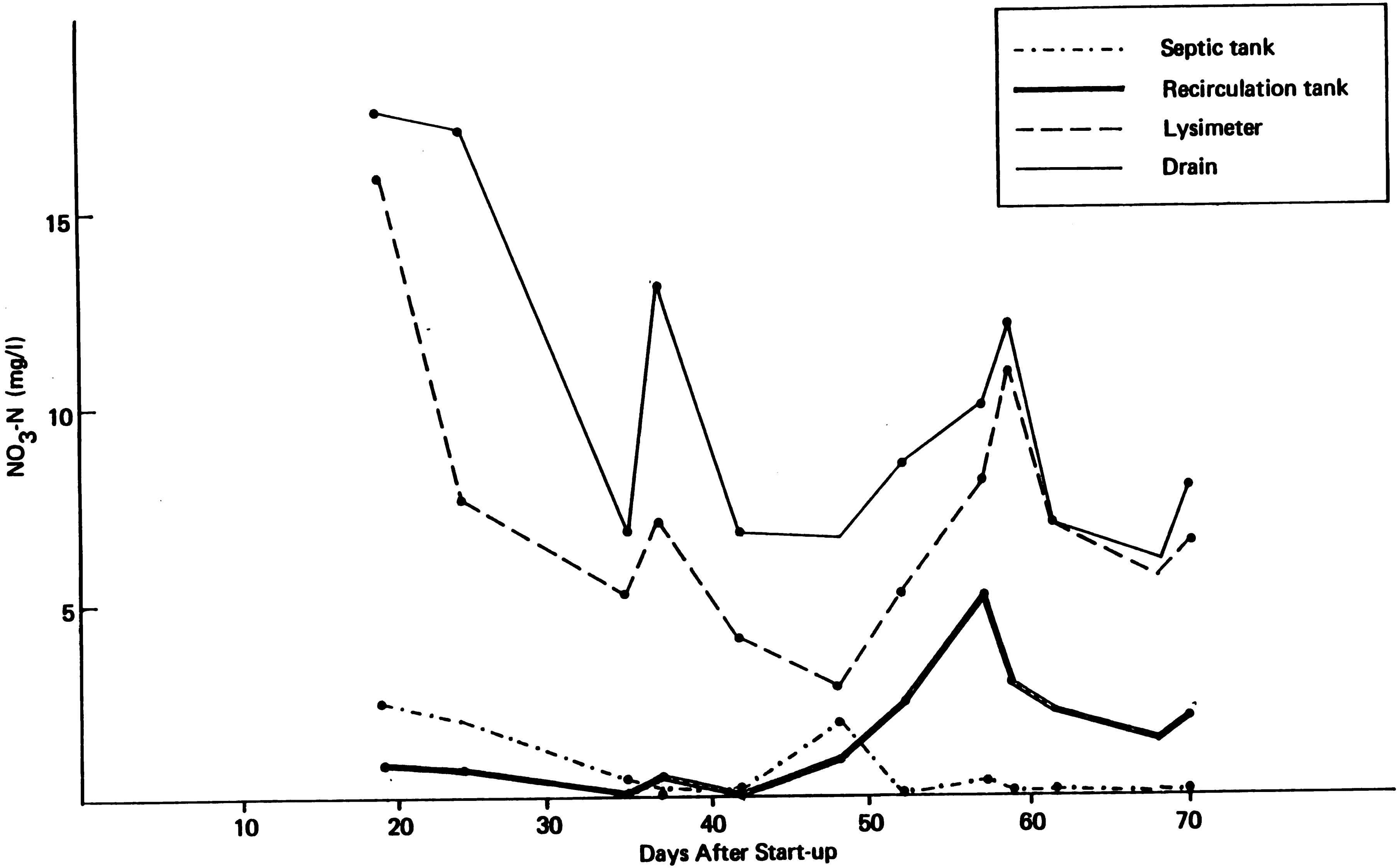

Figure 7. NO_3-N Control Columns

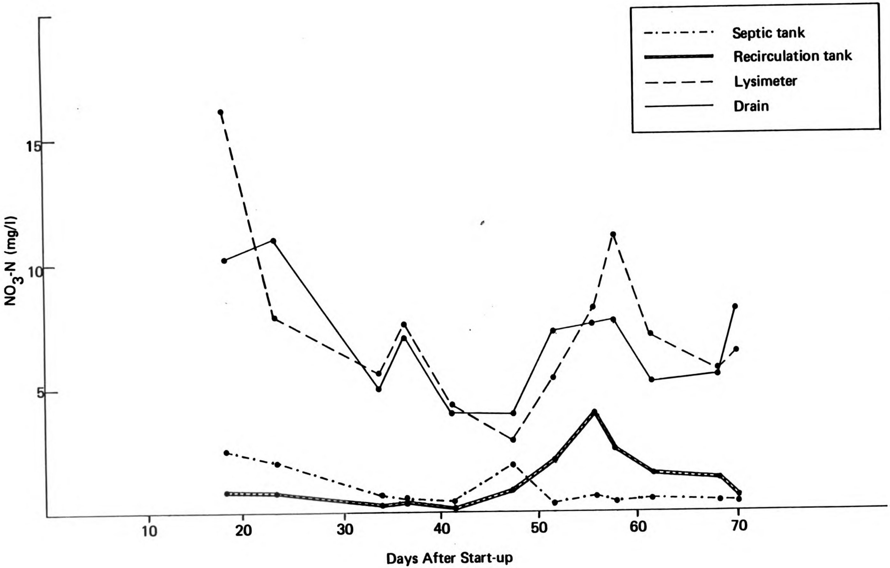

Figure 8. NO_3-N Treated Columns

Both treated and control columns showed much greater variability with respect to NO_3-N concentration in the lysimeters and drain. Nitrate-nitrogen in the control column drains were always higher than was observed in the lysimeter samples. When high NO_3-N levels were observed in the treated column lysimeters, concentration in the drain was lower by several mg/l. Otherwise the curves for the lysimeter and drain matched quite closely. This would suggest that denitrification was more effective in reducing high NO_3-N concentrations than low levels. The curves would also suggest that no denitrification was occurring in the control columns.

Statistical Analysis

Statistical analyses were performed to determine the significance at the 95 percent confidence level of the differences pointed out above. The analysis of variance procedure was used with a completely randomized block design. Blocking was done with time so that the variability between sampling dates could be separated from differences due to treatment effects. The experimental unit was the complete system of three columns and the recirculation tank. Each column was treated as a subsample within the unit. F tests were performed to determine if the differences in total nitrogen and NO_3-N concentrations between lysimeter samples and between drain samples of the two systems were significant.

The analysis of variance for total nitrogen concentrations between the control and treatment drains is presented in Table 2.

The F test showed that the difference was significant and the total nitrogen concentration in the treated column drains was lower than the control drains.

Table 2. AOV for total nitrogen concentration between filter drains.

Source	df	SS	MS	F
Block	9	701.796	77.977	6.998*
Treatment	1	213.570	213.570	19.168*
Error	9	100.274	11.142	
Sampling	40	87.223	2.181	
Total:	59	1102.863		

F = 5.12
*Significant at 95 percent probability level

The analysis of variance for NO_3-N concentrations in the column drains is presented in Table 3. The F test showed that the difference between treatments was significant and that the NO_3-N concentration in the treated column drains were lower than in the control column drains.

In order to determine if the differences observed could be attributed to the effect of adding corn to the saturated zone of the treated columns, the analysis of variance was performed for total nitrogen and NO_3-N concentrations in the unsaturated zone of both

Table 3. AOV for nitrate nitrogen concentration between filter drains.

Source	df	SS	MS	F
Block	11	628.397	57.127	5.677*
Treatment	1	172.980	172.980	17.189*
Error	11	110.695	10.063	
Sampling	48	209.097	4.356	
Total:	71	1121.169		

F = 4.84
*Significant at 95 percent probability level

sets of columns. The analysis of variance tables are presented in Table 4 and Table 5 for total nitrogen and NO_3-N respectively. The F tests showed that the differences between average concentrations of total nitrogen and NO_3-N in the unsaturated zone of both treatments was not significant. The level of treatment for nitrogen achieved in the unsaturated zone of the columns in both systems was the same.

In summary, there was significantly less total nitrogen and NO_3-N in the treated column drains than in the control column drains. The total nitrogen and NO_3-N concentrations in the lysimeter samples from the control and treatment columns were not significantly different. The variation among columns within a treatment was less than the variation due to experimental error as indicated by the sample mean squares when compared to the error mean square.

Table 4. AOV for total nitrogen concentration between filter lysimeters.

Source	df	SS	MS	F
Block	9	886.208	98.468	7.432*
Treatment	1	10.333	10.333	0.780ns
Error	9	119.238	13.249	
Sampling	40	237.680	5.942	
Total:	59	1253.456		

F = 5.12
*Significant at 95 percent probability level
ns Not significant

Table 5. AOV for nitrate nitrogen concentration between filter lysimeters.

Source	df	SS	MS	F
Block	11	694.018	63.093	7.302*
Treatment	1	12.169	12.169	1.408ns
Error	11	95.044	8.64	
Sampling	48	208.990	4.354	
Total:	71	1010.221		

F = 4.84
*Significant at 95 percent probability level
ns Not significant

Nitrogen Removal in Both Systems

Both systems were effective in removing nitrogen from the wastewater. The total nitrogen concentration in the column drains was approximately 70 and 80 percent lower than in the septic tank effluent in the control and treated systems respectively.

The major mechanism for nitrogen reduction was probably by nitrification of ammonia and organic nitrogen in the unsaturated zone of the columns and denitrification in the recirculation tank. Ammonia-N was reduced to nearly zero in the columns and NO_3-N made up about 90 percent of the total nitrogen in the drains from both systems indicating that nitrification in the columns was nearly complete. Only 12 percent of the total nitrogen in the recirculation tank was as nitrate. At a four to one recirculation rate one-fourth of the tank volume would be filled by unfiltered effluent and three-fourths by filtered effluent.

On October 5 the samples were collected after the recirculation tanks were dosed. If the assumption is true, then the NH_3-N concentration in the recirculation tank could be predicted using the concentration in the column drains and septic tank effluent. The septic tank effluent contained 48.6 mg/l of NH_3-N and the three control columns averaged 1.7 mg/l NH_3-N.

$$\begin{array}{r} 15\ \mathrm{l} \times 48.6\ \mathrm{mg/l} = 729\ \ \mathrm{mg} \\ \underline{+\ 45\ \mathrm{l} \times\ \ 1.7\ \mathrm{mg/l} = 76.5\ \mathrm{mg}} \\ 805.5\ \mathrm{mg} \\ 805.5\ \mathrm{mg} \div 60\ \mathrm{l} = 13.4\ \mathrm{mg/l} \end{array}$$

The observed NH_3-N concentration in the recirculation tank was 12.5 mg/l which supports the assumption that three-fourths of the tank volume was filtered effluent and one-fourth septic tank effluent.

Since the septic tank effluent contributed no NO_3-N, the NO_3-N concentration in the recirculation tank could be estimated if only dilution is considered. The NO_3-N concentration in the recirculation tank should be approximately three-fourths of the concentration in the column drains, or 7.5 mg/l NO_3-N in the control recirculation tank. The actual NO_3-N concentration was 1.6 mg/l. At an 8:1 recirculation rate the expected NO_3-N concentration would be even higher.

It is reasonable to attribute the lower observed NO_3-N concentration in the recirculation tank than expected to denitrification. The high BOD_5 in the septic tank effluent could deplete the dissolved oxygen in the column effluent when they are mixed in the recirculation tank, creating the anaerobic environment necessary for denitrification. Septic tank effluent has been proven in other works (Laak, 1981) to be an effective source of carbon for denitrification. Additionally, the relatively large recirculation tank (60 liters at 7.2 l/day) resulted in an eight day retention time which should have provided sufficient time for denitrification to occur.

Denitrification in the Treated System

It was postulated that total nitrogen would be reduced in the saturated zone of the treated columns by denitrification. Little change in nitrogen concentration was expected with movement of effluent through the saturated zone of the control system. Total nitrogen and NO_3-N concentrations near the bottom of the unsaturated zones of both systems were statistically the same. However, NO_3-N concentrations did not appear to be reduced in the saturated zone of the treated system; rather, NO_3-N concentrations appeared to increase in the saturated zone of the control system. Total Kjeldahl nitrogen remained unchanged in both systems and the increase in total nitrogen in the control system was accounted for by the increase in NO_3-N. When the column drains of the two systems are compared against each other, and the lysimeters are compared against each other, the data suggest that the two systems act similarly in the unsaturated zone and that denitrification in the saturated zone of the treated system could account for the lower NO_3-N concentrations there. The apparent increase in NO_3-N concentration in the saturated zone of the control column may have been an artifact of the experimental procedure.

When the column retention time is considered it is conceivable that some denitrification could occur in the saturated zone. If 45 percent porosity is assumed for the sand in the columns, the effluent storage volume in the saturated zone of each column was about 2.4 liters. At a dosing rate of 400 ml/hr, each column had a retention time of about six hours in the saturated zone. In addition to this, it would take several hours for the effluent to move through the unsaturated zone of the column. The quality of the effluent draining from the columns at any particular time would be partially a function of the effluent quality in the recirculation tank ten or more hours earlier, when the dose was applied.

In order to verify this, three of the columns were flushed for twenty-four hours with fresh water. They were then given two consecutive 400 ml doses with a 500 mg/l chloride solution, followed by hourly 400 ml doses of fresh water. The column drains were sampled every hour and analyzed for chlorides. Chloride concentration above the background levels were not detected in any column drains for 10 hours. At ten hours, two of the columns showed slightly elevated chloride concentrations in the drains and at 11 hours all three columns had elevated chloride concentrations in the drains. The maximum chloride concentration at 11 hours was 165 mg/l in one column that had been given a one liter dose the previous hour. The other two columns had chloride concentrations of about 100 mg/l. At the four to one recirculation rate the minimum retention time in the column would have been on the order of 11 hours, of which about half was probably in the saturated zone. Earlier works with methanol (Dolakia, 1970; Sikora, 1974) and with greywater (Laak, 1981) as energy sources indicated that most of the denitrification could be accomplished in less time. While corn is probably not as effective a carbon source as methanol, six hours should have been sufficient for some denitrification to occur. Even at the higher recirculation rates, the retention time was three hours; more than was required in Sikora's (1974) study to completely denitrify NO_3-N at 40 mg/l.

The apparent increase in NO_3-N concentration between the lysimeter and the drain in the control columns is another problem and may be addressed by examining the sampling methods and the dosing method. The recirculation tanks were dosed once a day. Each hour the tank volume was reduced by 0.3 liters as one-fourth of the column effluent was diverted to the floor drain. With each pass through the column, a portion of the incoming nitrogen was nitrified, then denitrified upon returning to the recirculation tank, resulting in a gradual decrease in the total nitrogen concentration in the tank with time.

The water samples were collected from the recirculation tank at the end of a twenty-four hour cycle. The drain samples were collected at the same time, but they represent wastewater that had been applied 11 or 12 hours previously, at presumably higher nitrogen concentrations. The samples taken with the lysimeters were twenty-four hour composite samples and represent the average concentration over one cycle. Because of this, each set of samples represents a different aspect of the treatment process.

Comparisons across treatments of lysimeter vs lysimeter, drain vs drain, and tank vs tank, can be made because each comparison tests the same process. Comparisons within a system are not valid. The apparent increase observed in the control column may only represent the fact that the total nitrogen concentration in the effluent as it moved through the system was higher than the twenty-four average.

With this in mind, it would appear that the same process is occurring in the unsaturated zone of both treatments where no differences were detected in NO_3-N or total nitrogen concentrations. In the drains, the treated system had significantly lower average NO_3-N concentration than the control, while both systems were nearly equal in TKN concentration. Denitrification in the saturated zone would explain the differences.

Direct comparisons within a treatment could be made if the recirculation tank had been dosed several times a day to maintain a fairly constant nitrogen concentration in the tank, or composite samples had been taken over twenty-four hours from the recirculation tanks and the drains as well as the lysimeters.

Implications of the Results

The results indicated that NO_3-N in the filter effluent from a recirculation sand filter can be reduced by denitrification in the filter. Denitrification in the treated system was not complete and no attempt was made to optimize the process. Increasing the column retention time by decreasing the loading rate could lead to more complete denitrification. Corn may not be a suitable carbon source. Assuming complete decomposition of the corn, complete nitrification of influent nitrogen, and that all the carbon released is used for denitrification, an estimate of the useful life of the system can be made:

$$(50 \text{ g corn})\ (1.1 \text{ g COD/g corn})\ \left(\frac{14\text{g N}}{40\text{g COD}}\right) = 19.25 \text{ g N denitrified}$$

$$19.25 \text{ g N} \div 40 \text{ mg/l total N in influent} = 481 \text{ l influent}$$

$$481 \text{ l} \div 2.2 \text{ l/day} = 219 \text{ days}$$

After about 200 days (actually considerably less) denitrification would stop. Increasing the quantity of corn increased the BOD_5 levels in the column effluent so either small quantities of corn would need to be added periodically to maintain denitrification, or a large quantity of more slowly decomposable material could be used.

Another alternative to corn may be to utilize carbon present in the recirculation tank by injecting a small quantity of recirculation tank effluent into the saturated zone of the filter at the same time the dose is applied to the filter. This could be done with the existing recirculation pump by running a branch off the filter supply pipe and diverting a small portion of the effluent to a manifold located at the bottom of the filter. Finally, it may be that complete denitrification in a recirculating sand filter is not possible without contributing to high BOD_5 levels in the effluent. Further work is needed to optimize the denitrification process.

It is apparent that overall treatment for nitrogen will not be greatly different in either system, since much of the denitrification occurs in the recirculation tank. A simpler means of reducing nitrogen in wastewater may be to take advantage of the denitrification occurring in the recirculation tank and increasing the recirculation rate. This could be done by either increasing the hydraulic loading rate on the filter or increasing the filter surface area and maintain the hydraulic loading rate. An added benefit of this method would be the removal of COD in the recirculation tank. If the filter effluent contains 20 mg/l NO_3-N the amount of COD removed can be predicted by the following equations:

$NO_3^{+5} \longrightarrow N_2^{0} + 5e^-$

8g COD used/mole e^- transferred

40g COD used/mole of N removed

40g COD/14 g N = 2.86 g COD removed per g of N denitrified

20mg/l NO_3-Nx2.86mg COD/mg N removed = 57.2mg COD removed/l

The result would be to decrease the COD loading on the filter and perhaps decrease the incidence of failure due to clogging.

Overall System Performance

Apart from the clogging problems noted earlier, the laboratory systems compared favorably to the Kirtland Community College field system. Both systems produced a highly nitrified effluent with essentially no NH_3-N or Kjeldahl nitrogen. The Kirtland Community College system reduced total nitrogen from 130 mg/l in the septic tank effluent to 27.3 mg/l in the filter effluent with 80 percent of the effluent as NO_3-N. That represented a 75 percent reduction in nitrogen. The laboratory septic tank effluent contained considerably less total nitrogen (38.0 mg/l). This was reduced by 73 percent in the control column drain to 10.9 mg/l, and was approximately 90 percent as NO_3-N.

The incidence of clogging was not reported in the Ralph (1978) study, but did occur in the columns used by Stewart (1979) at low loading rates. Clogging in the lab may have been attributed to the high hydraulic loading rates following the failure of the recirculation pump control clock or may be a function of the small surface area of the columns. A contributing factor may have been lack of air movement in the lab which would reduce surface drying between doses. In the field, natural air currents would help dry the filter surface.

CHAPTER SIX

SUMMARY AND CONCLUSIONS

The effect of incorporating a saturated zone with a supplemental source of carbon on nitrogen reduction in a recirculating sand filter was evaluated using columns in the laboratory. Samples were collected from the saturated and unsaturated zones of each column, the recirculation tank and septic tank. The samples were analyzed for TKN, NH_3-N, and NO_3-N concentration. The effluent quality data was analyzed using a random block design with subsamples to determine the significant differences in total nitrogen and NO_3-N concentrations between treatments in both the saturated and unsaturated zones of the columns.

The following conclusions were drawn from the study:

1. A highly nitrified effluent was produced in both sets of columns. NO_3-N accounted for approximately 90 percent of the total nitrogen in the column effluent.
2. Both systems were effective in removing total nitrogen from the wastewater. Neither system exceeded the 10 mg/l standard for NO_3-N in drinking water, but the control system did exceed 10 mg/l total nitrogen.

3. Adding cracked corn to the saturated zone of the filter did result in significantly lower NO_3-N and total nitrogen concentration in the final effluent when compared to the system with no supplemental carbon.
4. Denitrification in the filter of a recirculating sand filter could be used as a means of reducing nitrogen discharge from small scale wasteflows.
5. Efforts should be made to optimize the process by looking at different carbon sources and different loading rates/retention times.
6. The effect of increasing the recirculation rate on denitrification in the recirculation tank should be studied as a potential means of reducing NO_3-N concentration in wastewater.

REFERENCES

Brandes, M., N. A. Chowdry, W. W. Cheng. "Experimental Study on Removal of Pollutants from Domestic Sewage by Underdrained Soil Filters." Home Sewage Disposal, ASAE Symposium Proc., 1974, pp 29-36.

Dholakia, S. G. Methanol Requirement and Temperature Effects in Wastewater Denitrification. USEPA 17010 DHT 8-70, 1970.

Enfield, Carl G. "Servo Controlled Optimization of Nitrification-Denitrification of Wastewater in Soil." Journal of Environmental Quality, Vol. 6, No. 4, 1977, pp 456-458.

EPA Technology Transfer. Alternatives for Small Wastewater Treatment Systems. EPA 625/4-77-011, 1977.

EPA Technology Transfer. Onsite Wastewater Treatment and Disposal Systems. 1980.

Erickson, A. E., B. G. Ellis, J. M. Tiedge. Soil Modification for Denitrification and Phosphate Reduction of Feedlot Waste. EPA 660/2-27-057, 1974.

Hines, Michael, R. E. Favreau. "Recirculating Sand Filters: An Alternative to Traditional Sewage Absorption Systems." Home Sewage Disposal, ASAE Symposium Proc., 1974, pp 130-137.

"HNU Ion Selective Electrodes, Ammonia Electrode Manual ISE 10-10-00." HNU Systems, Inc., Newton, MA, 1978.

Laak, Rein, M. ASCE, Mary A. Parese, and Raymond Costello. "Denitrification of Blackwater with Greywater." Journal of the Environmental Engineering Div., ASCE, Vol. 107, No. 3, June 1981, pp 581-590.

Magdoff, F. R., J. R. Bouma, and D. R. Keeney. "Columns Representing Mound-Type Disposal Systems for Septic Tank Effluent: I. Soil Water and Gas Relations." Journal of Environmental Quality, Vol. 3, No. 3, 1974, pp 223-228.

Magdoff, F. R., J. R. Bouma, and D. R. Keeney. "Columns Representing Mound-Type Disposal Systems for Septic Tank Effluent: II. Nutrient Transformations and Bacterial Populations." Journal of Environmental Quality, Vol. 3, No. 3, 1974, pp 228-234.

"Nitrate Ion Electrode Model 93-07, Instruction Manual." Orion Research Incorporated, Form 9307/9790, 1979.

Otis, R. J. and W. A. Ziebell, "A Report of an Investigation of a Subsurface Sand Filter Loaded with Septic Tank Effluent at the Cleveland Heights Elementary School, New Berlin, Wisconsin." Report to the Wisconsin State Department of Natural Resources and Department of Health and Social Services, SS S.M.P., University of Wisconsin, Madison, 1973.

Ralph, David Joseph. Alternative Filter Media for Use in the Recirculating Sand Filter System. M.S. Thesis, University of Illinois, 1977.

Repko, J. Personal communication, Michigan State University, Agricultural Engineering Department, Agricultural Pollution Laboratory (1980).

Sauer, D. K., W. C. Boyle, R. S. Otis. "Intermittent Sand Filtration of Household Wastewater Under Field Conditions." Journal of the Environmental Engineering Div., ASCE, Vol. 102, No. 1, 1976, pp 789-803.

Sikora, L. J., J. C. Converse, D. R. Keeney, and R. C. Chen. "Field Evaluation of a Denitrification System." Home Sewage Treatment, ASAE Symposium Proc., 1977, pp 202-207.

Sikora, L. J., D. R. Keeney. "Lab Studies on Stimulation of Biological Denitrification." Home Sewage Disposal, ASAE Symposium Proc., 1974, pp 64-73.

Standard Methods for the Examination of Water and Wastewater. 14th ed., American Public Health Association, Washington, D.C., 1976.

Stewart, L. W., B. L. Carlile, D. K. Cassel. "An Evaluation of Alternative Simulated Treatments of Septic Tank Effluent." Journal of Environmental Quality, Vol. 8, No. 3, 1979, pp 397-403.

GENERAL REFERENCES

Broadbent, F. E. "Factors Affecting Nitrification-Denitrification in Soils." Recycling Treated Municipal Wastewater and Sludge through Forest and Cropland. Pennsylvania State University Press, 1973, pp 232-245.

Gilbert, R. G. "Denitrifying Bacteria Populations and Nitrogen Removal in Soil Columns Intermittently Flooded with Secondary Sewage Effluent." Journal of Environmental Quality, Vol. 8, No. 2, 1972, pp 180-186.

Miller, John C. "Nitrate Contamination of the Water Table Aquifer by Septic Tank Systems in the Coastal Plain of Delaware." Water Pollution Control in Low Density Areas. Proceedings of a Rural Environmental Engineering Conference, 1975, pp 121-135.

Teske, Murl G. "Enhanced Treatment for Surface Discharge." Proceedings of the 6th National Conference, Individual Onsite Wastewater Systems, 1979, pp 137-145.

Walker, W. G., J. Bouma, D. R. Keeney, and P. G. Olcott. "Nitrogen Transformations During Subsurface Disposal of Septic Tank Effluent in Sands: I. Soil Transformations." Journal of Environmental Quality, Vol. 2, No. 4, 1973, pp 475-480.

Walker, W. G., J. Bouma, D. R. Keeney, and P. G. Olcott. "Nitrogen Transformations During Subsurface Disposal of Septic Tank Effluent in Sands: II. Ground Water Quality." Journal of Environmental Quality, Vol. 2, No. 4, 1973, pp 521-525.

APPENDICES

APPENDIX A

EFFLUENT DATA

A1: Effluent Data: Septic Tank

Sample date	TKN (mg/l as NH_3)	NH_3-N (mg/l)	NO_3-N (mg/l)	Total-N (mg/l)
9/6/81	29.6	29.3	2.5	32.1
9/11/81	55.0	35.7	2.0	57.0
9/22/81	18.5	13.7	0.6	19.1
9/24/81	25.6	28.2	0.5	26.1
9/29/81	53.1	49.5	0.4	53.5
10/5/81	61.8	48.6	1.9	63.7
10/9/81	--	16.9	0.2	--
10/14/81	--	46.7	0.6	--
10/16/81	31.2	22.2	0.2	31.4
10/19/81	31.6	25.5	0.3	31.9
10/25/81	37.4	24.5	0.3	37.7
10/28/81	27.8	24.9	0.3	28.1
Mean:	37.2	30.5	0.8	38.1

A2: Effluent Data: Control Recirculation Tank

Sample date	TKN (mg/l as NH_3)	NH_3-N (mg/l)	NO_3-N (mg/l)	Total-N (mg/l)
9/6/81	11.4	6.4	0.9	12.3
9/11/81	16.6	6.8	0.7	17.4
9/22/81	4.9	4.1	0.2	5.1
9/24/81	8.8	5.8	0.6	9.4
9/29/81	3.2	5.2	0.1	5.3
10/5/81	27.1	12.5	1.0	28.1
10/9/81	--	3.7	2.4	--
10/14/81	--	5.8	5.2	--
10/16/81	6.7	5.2	2.7	9.4
10/19/81	7.5	7.7	2.2	9.7
10/26/81	21.5	9.6	1.4	22.9
10/28/81	5.4	3.4	1.9	6.3
Mean:	11.3	6.4	1.6	12.6

A3: Effluent Data: Treatment Recirculation Tank

Sample date	TKN (mg/l as NH_3)	NH_3-N (mg/l)	NO_3-N (mg/l)	Total-N (mg/l)
9/6/81	6.2	3.6	0.6	6.8
9/11/81	7.9	3.8	0.6	8.5
9/22/81	4.0	3.6	0.2	4.2
9/24/81	7.1	4.0	0.3	7.4
9/29/81	2.1	4.0	0.1	2.2
10/5/81	25.2	16.5	0.9	26.1
10/9/81	--	2.3	2.1	--
10/14/81	--	9.9	3.8	--
10/16/81	4.3	4.0	2.6	6.9
10/19/81	7.5	5.5	1.4	8.9
10/26/81	13.6	6.8	1.3	14.9
10/28/81	10.0	4.4	0.6	10.6
Mean:	8.8	5.7	1.2	9.7

A4: Effluent Data: Control Lysimeter, Column 1

Sample date	TKN (mg/l as NH_3)	NH_3-N (mg/l)	NO_3-N (mg/l)	Total-N (mg/l)
9/6/81	3.1	0.0	7.7	10.8
9/11/81	0.4	1.3	6.6	7.0
9/22/81	0.5	0.8	3.8	4.3
9/24/81	0.7	0.3	5.5	6.2
9/29/81	0.4	1.5	2.6	3.0
10/5/81	2.3	1.2	1.5	3.8
10/9/81	--	0.3	3.6	--
10/14/81	--	0.7	7.6	--
10/16/81	1.5	0.3	10.8	12.3
10/19/81	1.5	0.5	7.1	8.6
10/26/81	1.4	0.3	6.8	8.2
10/28/81	0.9	0.1	7.0	7.9
Mean:	1.3	0.6	5.9	7.2

A5: Effluent Data: Control Lysimeter, Column 2

Sample date	TKN (mg/l as NH_3)	NH_3-N (mg/l)	NO_3-N (mg/l)	Total-N (mg/l)
9/6/81	3.3	0.1	22.8	26.1
9/11/81	0.4	0.1	9.5	9.9
9/22/81	0.4	0.7	6.8	7.2
9/24/81	0.5	0.1	8.6	9.1
9/29/81	0.3	0.9	5.2	5.5
10/5/81	3.6	2.4	3.2	6.8
10/9/81	--	2.0	6.9	--
10/14/81	--	3.5	9.0	--
10/16/81	1.5	0.3	10.8	12.3
10/19/81	1.0	0.3	7.7	8.7
10/26/81	1.2	0.2	5.2	6.4
10/28/81	1.0	0.1	7.0	8.0
Mean:	1.3	0.9	8.6	10.0

A6: Effluent Data: Control Lysimeter, Column 3

Sample date	TKN (mg/l as NH_3)	NH_3-N (mg/l)	NO_3-N (mg/l)	Total-N (mg/l)
9/6/81	2.7	0.1	17.4	20.1
9/11/81	1.7	0.3	7.2	8.9
9/22/81	0.4	0.6	5.7	6.1
9/24/81	0.4	0.1	8.2	8.6
9/29/81	0.3	1.4	5.0	5.3
10/5/81	2.1	1.9	4.0	6.1
10/9/81	--	0.4	5.6	--
10/14/81	--	1.2	8.3	--
10/16/81	1.6	0.4	11.3	12.9
10/19/81	1.3	--	5.9	7.2
10/26/81	1.1	0.2	5.2	6.3
10/28/81	1.1	0.1	5.7	6.8
Mean:	1.3	0.6	7.5	8.8

A7: Effluent Data: Treated Lysimeter, Column 4

Sample date	TKN (mg/l as NH_3)	NH_3-N (mg/l)	NO_3-N (mg/l)	Total-N (mg/l)
9/6/81	4.6	0.0	12.3	16.9
9/11/81	1.1	0.1	14.9	16.0
9/22/81	0.3	0.5	5.1	5.4
9/24/81	0.4	0.1	5.2	5.6
9/29/81	0.1	0.0	3.1	3.2
10/5/81	0.8	1.4	3.5	4.3
10/9/81	--	0.1	5.1	--
10/14/81	--	0.3	6.1	--
10/16/81	1.8	1.1	7.2	9.0
10/19/81	0.8	0.2	5.6	6.4
10.26/81	2.3	2.1	7.1	9.4
10/28/81	0.8	0.1	7.3	8.1
Mean:	1.3	0.5	6.9	8.4

A8: Effluent Data: Treated Lysimeter, Column 5

Sample date	TKN (mg/l as NH_3)	NH_3-N (mg/l)	NO_3-N (mg/l)	Total-N (mg/l)
9/6/81	1.4	0.0	13.3	14.7
9/11/81	1.4	0.0	7.7	9.1
9/22/81	0.2	0.0	5.5	5.7
9/24/81	0.3	0.1	5.5	5.8
9/29/81	0.2	2.4	3.1	3.3
10/5/81	0.5	1.7	1.6	2.1
10/9/81	--	0.2	3.3	--
10/14/81	--	1.3	5.2	--
10/16/81	1.9	0.6	6.9	8.8
10/19/81	1.0	0.2	4.7	5.7
10/26/81	1.0	0.2	5.0	6.0
10/28/81	0.6	0.1	5.9	6.5
Mean:	0.9	0.6	5.6	6.8

A9: Effluent Data: Treated Lysimeter, Column 6

Sample date	TKN (mg/l as NH_3)	NH_3-N (mg/l)	NO_3-N (mg/l)	Total-N (mg/l)
9/6/81	1.2	0.0	14.3	15.5
9/11/81	3.2	2.4	18.0	21.2
9/22/81	0.3	0.4	5.5	5.8
9/24/81	0.4	0.1	6.6	7.0
9/29/81	0.1	0.1	2.8	2.9
10/5/81	0.7	1.3	2.4	3.1
10/9/81	--	0.0	5.3	--
10/14/81	--	0.4	6.1	--
10/16/81	1.9	0.4	7.2	9.1
10/19/81	1.3	--	3.9	5.2
10/26/81	0.8	0.2	4.7	5.5
10/28/81	1.0	0.1	6.2	7.2
Mean:	1.1	0.5	6.9	8.3

A10: Effluent Data: Control Drain, Column 1

Sample date	TKN (mg/l as NH_3)	NH_3-N (mg/l)	NO_3-N (mg/l)	Total-N (mg/l)
9/6/81	2.7	0.3	15.5	18.2
9/11/81	0.4	0.9	10.3	10.7
9/22/81	0.8	0.3	7.4	9.2
9/24/81	0.4	1.8	13.5	15.2
9/29/81	0.1	0.0	7.7	7.8
10/5/81	1.4	1.2	6.9	8.3
10/9/81	--	1.0	8.6	--
10/14/81	--	0.3	10.7	--
10/16/81	1.3	0.4	15.4	16.7
10/19/81	0.9	0.1	7.4	8.3
10/26/81	0.6	0.1	7.1	7.7
10/28/81	0.6	0.0	8.3	8.9
Mean:	0.9	0.5	9.9	11.1

A11: Effluent Data: Control Drain, Column 2

Sample date	TKN (mg/l as NH_3)	NH_3-N (mg/l)	NO_3-N (mg/l)	Total-N (mg/l)
9/6/81	1.6	0.0	21.1	22.7
9/11/81	0.9	1.3	20.3	21.2
9/22/81	0.2	0.5	6.3	6.8
9/24/81	0.2	0.0	12.3	12.5
9/29/81	0.1	0.2	6.2	6.3
10/5/81	2.0	2.4	4.4	6.4
10/9/81	--	1.8	8.3	--
10/14/81	--	0.3	9.9	--
10/16/81	1.3	0.5	13.5	14.8
10/19/81	0.6	0.0	7.1	7.7
10/26/81	0.5	0.1	5.2	5.7
10/28/81	0.9	0.0	8.7	9.6
Mean:	0.8	0.6	10.3	11.4

A12: Effluent Data: Control Drain, Column 3

Sample date	TKN (mg/l as NH_3)	NH_3-N (mg/l)	NO_3-N (mg/l)	Total-N (mg/l)
9/6/81	2.0	0.0	16.1	18.1
9/11/81	0.8	1.0	21.1	21.9
9/22/81	0.2	0.4	6.8	7.0
9/24/81	0.3	0.9	13.5	14.4
9/29/81	0.1	0.0	6.2	6.5
10/5/81	1.0	1.5	8.2	9.7
10/9/81	--	0.9	8.6	--
10/14/81	--	0.2	9.4	--
10/16/81	2.0	0.2	8.2	10.2
10/19/81	0.8	0.1	6.5	7.3
10/26/81	0.6	0.1	5.0	5.6
10/28/81	2.5	0.0	6.4	8.9
Mean:	1.0	0.4	9.7	10.9

A13: Effluent Data: Treated Drain, Column 4

Sample date	TKN (mg/l as NH_3)	NH_3-N (mg/l)	NO_3-N (mg/l)	Total-N (mg/l)
9/6/81	2.5	0.1	8.0	10.5
9/11/81	0.6	0.6	7.4	8.0
9/22/81	0.2	0.9	5.1	6.0
9/24/81	0.2	0.0	6.6	6.8
9/29/81	0.1	0.1	3.5	3.6
10/5/81	0.7	0.3	4.4	5.1
10/9/81	--	0.4	6.6	--
10/14/81	--	0.2	6.4	--
10/16/81	1.5	0.2	9.4	10.9
10/19/81	0.9	0.0	5.4	6.3
10/26/81	0.7	0.0	6.2	6.9
10/28/81	2.0	0.0	10.3	12.3
Mean:	0.9	0.2	6.6	7.6

A14: Effluent Data: Treated Drain, Column 5

Sample date	TKN (mg/l as NH_3)	NH_3-N (mg/l)	NO_3-N (mg/l)	Total-N (mg/l)
9/6/81	2.5	0.1	10.9	13.4
9/11/81	0.1	0.1	9.1	9.2
9/22/81	0.2	0.9	5.1	6.0
9/24/81	0.3	0.8	8.2	9.0
9/29/81	0.1	0.0	4.8	4.9
10/5/81	1.1	1.6	4.2	5.8
10/9/81	--	0.2	8.3	--
10/14/81	--	0.2	7.9	--
10/16/81	1.1	0.1	7.2	8.2
10/19/81	0.9	0.0	5.2	6.1
10/26/81	0.5	0.1	4.7	5.2
10/28/81	0.9	0.0	6.4	7.3
Mean:	0.8	0.3	6.8	7.5

A15: Effluent Data: Treated Drain, Column 6

Sample date	TKN (mg/l as NH_3)	NH_3-N (mg/l)	NO_3-N (mg/l)	Total-N (mg/l)
9/6/81	2.8	0.1	11.3	14.1
9/11/81	0.5	0.0	16.1	16.6
9/22/81	0.1	0.2	4.4	4.6
9/24/81	0.2	0.0	6.0	6.2
9/29/81	0.1	0.1	4.4	4.5
10/5/81	0.6	0.6	3.2	3.8
10/9/81	--	0.4	6.9	--
10/14/81	--	0.1	8.3	--
10/16/81	0.8	0.1	6.3	7.1
10/19/81	1.0	0.1	4.7	5.7
10/26/81	0.3	0.0	5.4	5.7
10/28/81	0.8	0.0	8.3	9.1
Mean:	0.7	0.1	7.1	7.7

APPENDIX B

ANALYSIS OF FILTER SAND

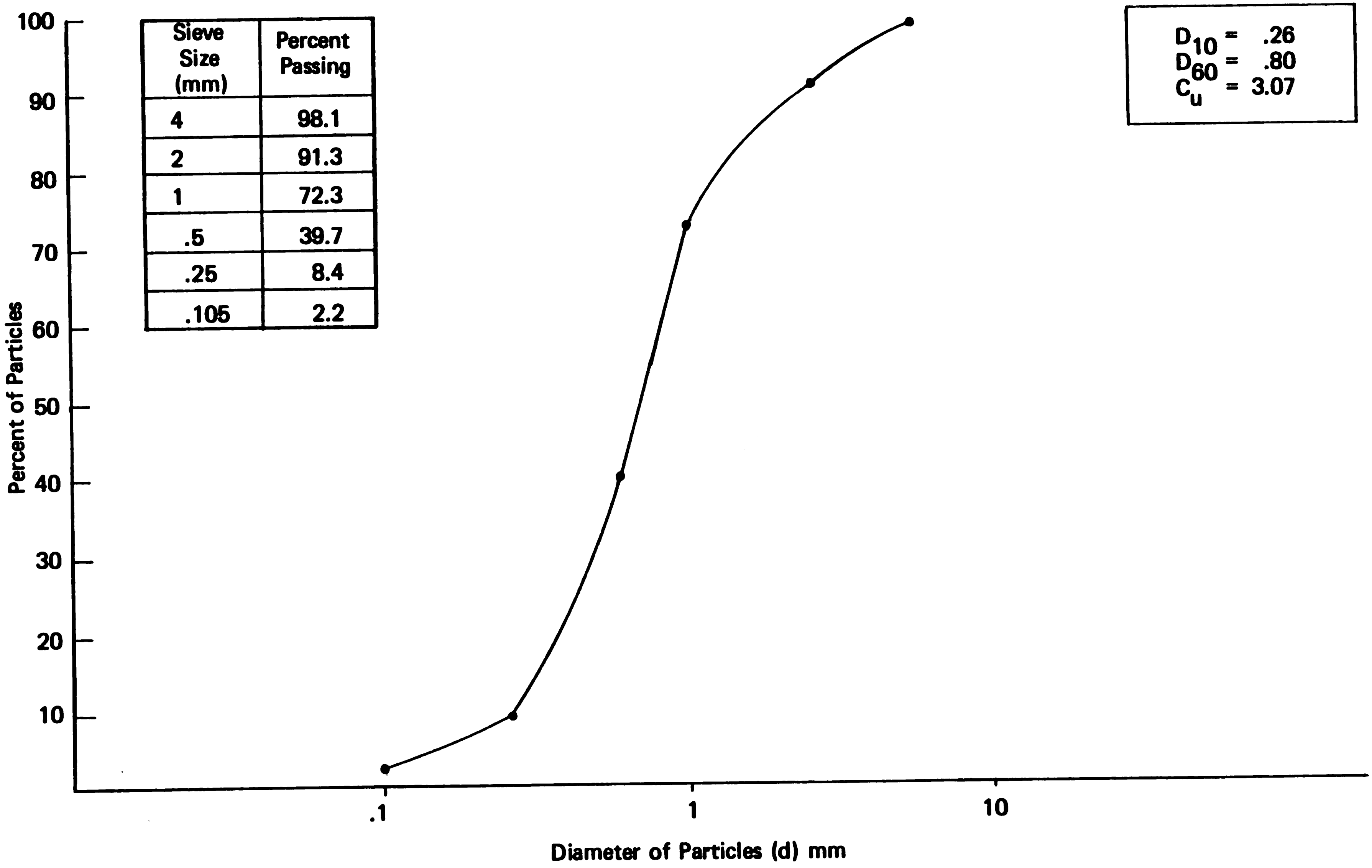

Figure B1: Particle Size Analysis