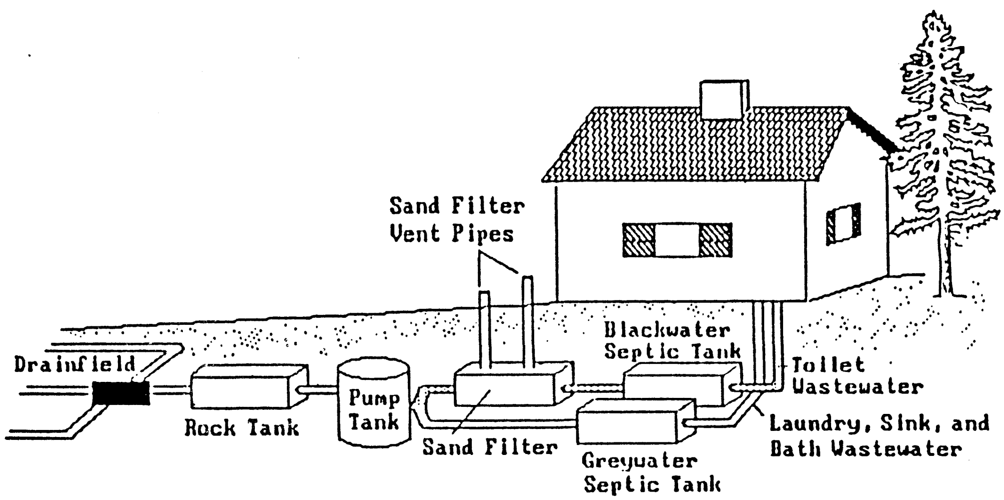
An Assessment of the Nitrogen Removal Efficiency and Performance of RUCK Septic Systems in the New Jersey Pinelands



The RUCK System

December 1990

New Jersey Pinelands Commission

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Abstract

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The RUCK system is an innovative nitrogen-reducing septic system approved for experimental use in the New Jersey Pinelands. It is designed to reduce wastewater nitrogen through denitrification. A household's greywater (washwater) is plumbed separately from the blackwater (toilet water). The blackwater enters an aerobic sand filter where it is nitrified. The greywater by-passes the sand filter to serve as a carbon source for the denitrification process which occurs under anaerobic conditions in a pump tank and a rock tank. This study determined that the factors which affect the nitrogen attenuating ability of the RUCK system include the sand filter nitrification rate, the pump tank and rock tank denitrification rate, and the greywater ammonia and organic nitrogen concentration.

The Pinelands Commission monitored 18 RUCK systems at quarterly intervals. Each system was monitored for a period of three years. Fifteen of the systems monitored were residential systems and three were non-residential. The average total nitrogen in the residential system rock tank effluent was 19.9 mg/l (standard error = 2.1). Ten of these systems had rock tank effluent nitrogen concentrations of 20 mg/l or less. Residential system nitrification rate averaged 57% (standard error = 5.2). The denitrification of the nitrified fraction of the total nitrogen for the residential systems was consistently 100% or nearly 100%. Nitrification was the factor that limited residential RUCK system nitrogen removal. The average total nitrogen in the non-residential system rock tank effluent was 42.7 mg/l (standard error = 7.6). For the non-residential systems, denitrification or nitrogen in the greywater limited nitrogen removal.

Residential RUCK systems provide a degree of nitrogen removal from household wastewaters. Based on an average of 19.9 mg/l of nitrogen present in Pinelands residential RUCK system rock tank effluent, a minimum parcel size of 1.4 to 1.5 acres is required to meet the Pinelands Management Plan 2 mg/l nitrate-nitrogen groundwater standard. Because various mechanical and installation problems were found at certain Pinelands systems, it is important that proper system performance be ensured by inspection of the systems during construction, prior to use, and at defined intervals while the system is in use. There also must be a method of ensuring initial quality control and continued maintenance for the installed systems. Non-residential RUCK systems tend to lack a greywater carbon source and may not passively be able to produce low nitrogen concentration effluent. The addi-

tion of a carbon source to the greywater of non-residential systems would be an alternative, only if the carbon source had a low nitrogen concentration and the carbon source addition mechanism was reliable. Additional study is warranted to determine the long term nitrification efficiency and clogging potential of the sand filter, to more clearly define factors affecting RUCK system nitrification and denitrification rates, to determine ways of decreasing the pump failure rate when pumps are required, to determine ways of reducing system cost without sacrificing function, and to determine whether changes in sand filter or vent pipe design would increase the nitrification rate while maintaining the system's passive feature.

Acknowledgments

Thanks are extended to the owners of the eighteen monitored RUCK systems for their cooperation during this study. Thanks are also due to Robert Nicholson for his work on the formative stages of the study, the Burlington County Health Department for the laboratory analyses, and Dr. Art Gold, Bonnie Lamb, and George Loomis of the University of Rhode Island for having TOC analyses run on Pinelands samples, for supplying RUCK data from their monitoring programs, and for their helpful advice and comments. Comments and suggestions provided by Dr. Rein Laak and information on RUCK system construction provided by Len Rusciani during the course of the study are also appreciated.

Finally, Pinelands Commission staff are acknowledged for their assistance in data entry, data review, and the preparation of the bi-annual progress reports and this final report.

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I. Introduction

IA. Purpose

The Pinelands is a relatively undeveloped area of over a million acres in southern New Jersey located near the center of the Washington-to-Boston metropolitan corridor (Figure 1). The groundwater in the Pinelands is highly susceptible to contamination due to the porosity and low chemical activity of the region's sandy and acidic soils. One major source of groundwater contamination is effluent from conventional on-site septic systems (Pinelands Comprehensive Management Plan, 1980; DeWalle and Schaff, 1980; Ritter and Chirnside, 1984). Nitrogen in septic system effluent is a primary concern because excessive concentrations of nitrate-nitrogen (NO_3-N) can present public health hazards such as methemoglobinemia in infants and possibly some forms of gastrointestinal cancer (Canter and Knox, 1985). Nitrate can also present ecological hazards such as eutrophication and invasion of non-native species in Pinelands aquatic and wetland habitats (Pinelands Comprehensive Management Plan, 1980; Ehrenfeld, 1983; Morgan and Philipp, 1986).

Although total Kjeldahl nitrogen (TKN), composed of ammonium (NH_4^+) + organic nitrogen, is the primary form of nitrogen in septic tank effluent, once in the aerobic drainfield the TKN is either retained in the "crust" zone by adsorption or rapidly oxidized (nitrified) to the nitrate form (Reneau, 1977; Andreoli et al., 1979, Gold et al., 1990). Thus, nitrate is the predominant form of nitrogen leaching below conventional septic system drainfields. Because nitrate is soluble and highly mobile it leaches rapidly through the sandy Pinelands soil to the groundwater where it is not expected to undergo any further chemical changes and is reduced in concentration only through dilution (Walker et al., 1973; Pinelands Comprehensive Management Plan, 1980).

Due to the great potential for nitrate contamination of Pinelands groundwater by septic systems, the Pinelands Commission requires that the parcel on which a septic system is located be large enough to ensure that the nitrate-nitrogen (NO_3-N) concentration in the groundwater leaving the parcel will not exceed 2 mg/l. Using an areal dilution model, the Commission estimates that a typical residential unit with a conventional septic system requires a lot size of at least 3.2 acres (Brown, 1980; Pinelands Comprehensive Management Plan, 1980). However, because some innovative septic systems have been shown to reduce nitrogen levels in wastewater, the Pinelands Commission permits their use for units on smaller sized parcels. The lot sizes are reduced in proportion to the nitrogen concentration reduction attributed to the particular system. The RUCK system is an innovative septic system designed by Dr. Rein Laak while at the University of Connecticut. Its specific purpose is to promote nitrogen removal

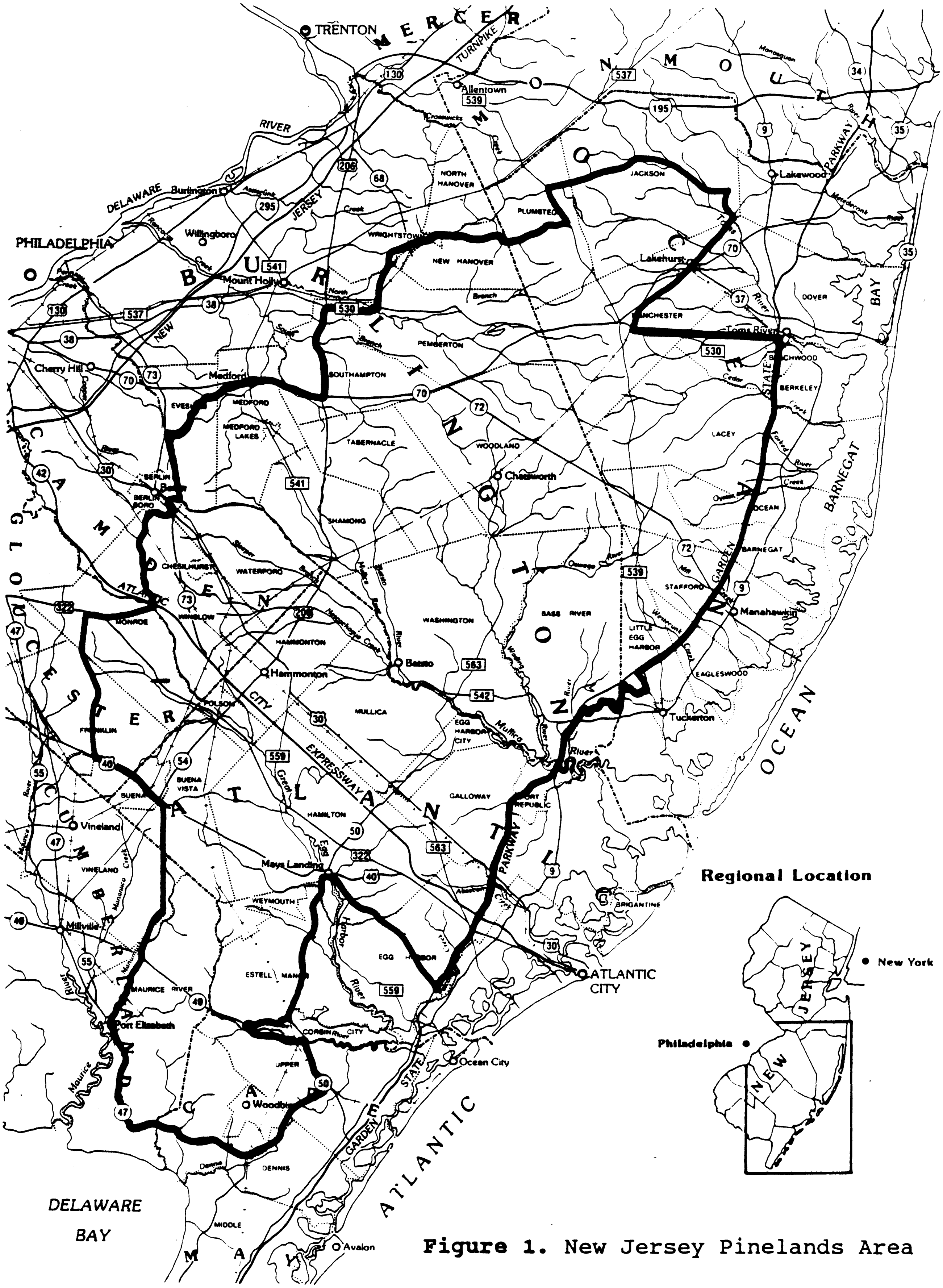


Figure 1. New Jersey Pinelands Area

through nitrification followed by denitrification (Laak et al., 1981; Laak, 1982). In December 1983, the Pinelands Commission established a policy permitting the experimental use of the RUCK septic system in the Pinelands on the condition that additional testing of the system's nitrogen reducing ability be done. In this report, the results of the Commission's five year study which assessed the RUCK system's overall performance, including its effectiveness in removing nitrogen from wastewater, are presented. The objectives of this study are: 1. to access the effectiveness of the RUCK system in reducing final effluent nitrogen levels in wastewater; and 2. to determine the minimum parcel size required to meet the 2 mg/l nitrate-nitrogen standard for point and non-point source discharges in the Pinelands (N.J.A.C. 7:50-6.84).

IB. RUCK System Use in the New Jersey Pinelands

From the time the RUCK system was permitted for experimental use in the Pinelands, approximately 413 Pinelands development applications have been approved by the Pinelands Commission with the condition that alternative or innovative septic systems be used. These include RUCK systems and pressure dosed systems (also currently under experimental consideration by the Pinelands Commission). At one time, waterless toilets were also included; however, approval of waterless toilets on undersized lots (< 3.2 acres) was discontinued in July 1988. As of November 1990, approximately eighty-eight RUCK systems had been constructed in the New Jersey Pinelands.

To meet the 2 mg/l nitrate-nitrogen groundwater standard of the Comprehensive Management Plan, the experimental RUCK systems in the Pinelands have been constructed on minimum parcel sizes of one acre. The one acre minimum parcel size for the RUCK system was determined using Brown's (1980) nitrate dilution model along with an assumed nitrogen input of 40 mg/l (Hickey and Duncan, 1966; Trela and Douglas, 1979; Canter and Knox, 1985) and an assumed nitrogen removal of 65%. The 65% nitrogen removal assumption was a conservative assumption based upon a preliminary study of the RUCK system by its designer (Laak, 1982). In the event that the RUCK system did not reduce the nitrogen concentration as expected, the one acre parcel size would allow a sufficient margin of safety to ensure that the 10 mg/l potable water nitrate-nitrogen standard set by the New Jersey Department of Environmental Protection be met (N.J.A.C. 7:10-5).

IC. The RUCK System Design

The RUCK system design is similar to that of a conventional septic system in that its components are buried and it makes use of conventional septic tanks and a conventional drainfield. A diagram of the design of a typical RUCK system is shown in Figure 2.

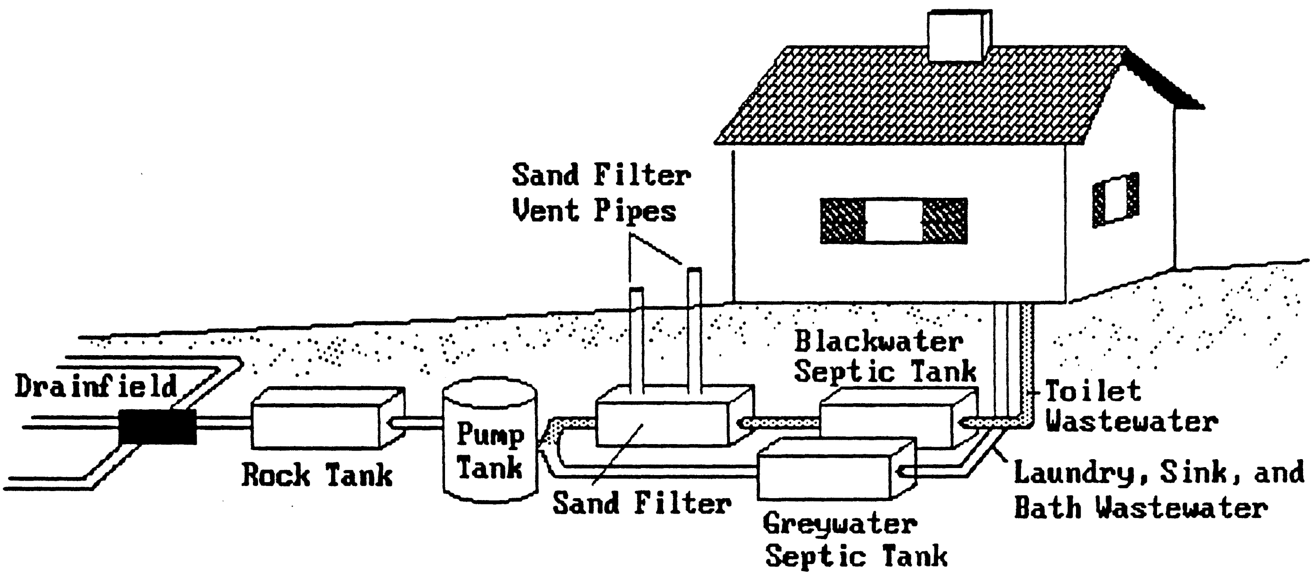


Figure 2: Diagram of the RUCK System Design (not to scale)

The RUCK system design differs from that of a conventional septic system in that it includes nitrification and denitrification components (the sand filter and rock tank, respectively) which are located between conventional septic tanks and a conventional drainfield. In flat terrain the RUCK system may also require a pump tank and pump in order to lift effluent from the bottom of the sand filter to the top of the rock tank.

The RUCK design further differs by separating the blackwater wastestream from the greywater wastestream through the use of two septic tanks. The greywater wastestream serves as a carbon source for the denitrification process and usually consists of all the non-toilet wastewater (washwater). The blackwater wastestream consists of toilet wastewater. From the septic tank, the blackwater enters the aerobic sand filter. In the sand filter, the blackwater TKN or a percentage of the blackwater TKN, is oxidized (nitrified) to nitrate-nitrogen. The blackwater exiting the sand filter is called filtered blackwater. The filtered blackwater contains nitrate- and nitrite-nitrogen (nitrite is an intermediate in the nitrification process; usually little nitrite is present) and any TKN that was not nitrified in the sand filter. The sum of the filtered blackwater nitrate, nitrite, and TKN equals the filtered blackwater total nitrogen concentration. The filtered blackwater then mixes with the greywater as it enters either the pump tank or the rock tank (some systems have no pump tank). In the rock tank (and/or the pump tank), the nitrate produced in the sand filter is reduced (denitrified) to nitrogen gas which dissipates into the atmosphere. From the rock tank, the combined blackwater and greywater effluent (final effluent) enters the drainfield.

ID. Nitrogen Removal and Other Features of the RUCK System

The RUCK system provides for nitrogen removal via the processes of nitrification and denitrification which occur in the sand filter and rock tank, respectively (denitrification also occurs in the pump tank if one is present). Nitrification is the oxidation of ammonium (NH_4^+) to nitrate (NO_3^-) under aerobic conditions. Denitrification is the subsequent reduction of the nitrate produced by nitrification to nitrogen gas. Denitrification occurs in anaerobic conditions and in the presence of a carbon source such as greywater (washwater). Complete explanations and condensed chemical equations for various steps in the nitrogen cycle are given in Appendix 1.

In addition to the nitrification and denitrification processes, special features of the RUCK system include: 1. the use of greywater (washwater) as the sole carbon source for denitrification; 2. passive vents supplying oxygen to the aerobic sand filter; and 3. by-passes for the sand filter and the rock tank allowing it to function as a conventional system if either the sand filter or the rock tank would clog.

II. Materials and Methods

IIA. Study Systems

Eighteen RUCK septic systems were included in the Pinelands RUCK monitoring program. Fifteen of these systems were at single family homes which were occupied year-round and in which laundry was done on the premises. The residences had an average of 3.6 occupants with the range being one to six occupants. Three of the RUCK systems were at commercial establishments which included a doctors office, a service station with a convenience store, and a small shopping center. The shopping center was composed of an antique shop, a bridal shop, a music store, and a restaurant-deli. Each of the residential and non-residential RUCK systems were constructed according to design criteria established by Dr. Rein Laak (Laak et al., 1981; Laak, 1982; Laak, 1986) under the supervision and approval of a New Jersey RUCK system engineer who was licensed by Dr. Laak.

IIB. Sample Collection

At each system, wastewater samples were collected from the greywater tank, the outlet of the sand filter (filtered blackwater), the pump tank (a greywater and filtered blackwater mixture), and the outlet of the rock tank (final effluent). Beginning in July 1989, samples from the blackwater septic tank were collected from systems which had accessible blackwater septic tanks. Each sample was collected in a 500 ml glass-stoppered bottle using a Masterflex portable pump. The bottle and the pump tubing were thoroughly rinsed with the effluent before sample collection. Temperature was determined in the field. Samples were placed on ice and transported immediately to the Burlington County Health Department laboratory, a New Jersey state certified laboratory, for chemical analysis.

Each system was sampled every three months starting between four to six months after the home or building became occupied. Systems were sampled over a three year period giving a total of twelve sample dates per system (exceptions are two of the commercial systems which were late additions to the monitoring program and one residential system which had a malfunctioning pump that was never repaired). Systems were added to the monitoring program as they were constructed and occupied. The first system was sampled in September 1985, and the final sample was collected from the last system in June 1990.

IIC. Laboratory Analysis

Samples were analyzed for TKN (total Kjeldahl nitrogen), NO_2-N (nitrite-nitrogen), NO_3-N (nitrate-nitrogen), pH, and chloride. Beginning in March 1988, sample temperature was also measured at the time of collection. Total Kjeldahl nitrogen, NO_2-N, NO_3-N, and chloride were each measured within 24 hrs of sample collection, and pH was measured immediately upon arrival at the laboratory. Quality controls including standards, spikes, and triplicate samples were run on each set of analyses to check precision and accuracy. TKN analysis was by the Kjeldahl nitrogen procedure (Standard Methods, section 420, 1980), nitrate- and nitrite-nitrogen analyses were by colorimetric measurement using the cadmium reduction procedure (U.S. EPA, section 353.2, 1983), pH was measured by direct meter (Standard Methods, section 423, 1980), and chloride analysis was by the mercuric nitrate procedure (Standard Methods, section 407b, 1980).

IID. Data Analysis

For the measured parameters, means and standard errors from a three year period were determined for each monitored RUCK system. Mean pH was calculated by conversion of the pH values to H+ concentrations. Grand means and standard errors were also determined for the parameter averages of all the systems. A chi-square test of normality was run on the mean final effluent total nitrogen values in order to determine whether the values were normally distributed.

Factors which affect RUCK system performance were identified through correlation analysis and graphical analysis. Total nitrogen inputs to the RUCK systems were estimated using U.S. EPA standardized flow ratios (U.S. EPA, 1980) and RUCK system nitrogen removal was calculated based on these estimates.

The nitrogen removal efficiency of Pinelands residential RUCK systems was compared to that of Pinelands non-residential RUCK systems, that of residential systems located in Charlestown, Rhode Island and studied by the University of Rhode Island, and that of one-fifth scale replicated systems also studied by the University of Rhode Island. The mechanical performance of Pinelands RUCK systems was compared to that of the Rhode Island RUCK systems, that of a Massachusetts RUCK test installation (Dudley et al., 1989), and that of a non-passive RUCK system installed at a California Department of Transportation inspection station (Danielson, 1989).

IIE. Homeowner Questionnaires

Prior to sampling their systems, owners of RUCK systems chosen for monitoring were asked to complete an owner questionnaire regarding factors which could affect the wastewater quality and/or the performance of their RUCK system (for example, the number of laundry loads per week, specific products disposed of in the septic system, and water-saving devices in use). At the completion of the RUCK monitoring program, all RUCK system owners, including those whose systems were not monitored, were sent a survey questionnaire requesting information concerning the operation and installation of their RUCK system and their personal satisfaction or dissatisfaction with their RUCK system. A summary of the results for both the owner and survey questionnaires is presented in Appendix 2. At the completion of the RUCK monitoring program, all RUCK systems not included in the monitoring program were inspected to determine whether they were properly installed and functioning satisfactorily. A summary of the inspection results is presented in Appendix 3.

III. Results and Discussion

IIIA. Total Nitrogen in Septic Tank Effluent

RUCK septic tank effluent includes greywater and blackwater, which are initially kept separate. Although blackwater is defined as toilet wastewater, sometimes the bathroom washwater is included with the blackwater. The greywater would then include only the kitchen and laundry wastewater. Of the fifteen residential RUCK systems monitored, ten of the households were plumbed such that the greywater consisted of all non-toilet wastes, and one household (system 4) was plumbed such that the greywater consisted of only kitchen and laundry wastewater. The greywater plumbing was not determined for the four remaining households (systems 1, 2, 10, and 12).

The average greywater total nitrogen (TKN + NO_3 + NO_2) concentration for the fifteen Pinelands residential RUCK systems was 13.3 mg/l (standard error = 0.9 mg/l; range = 8.1 - 21.9 mg/l). The average greywater total nitrogen concentration for the three Pinelands non-residential RUCK systems was 31.8 mg/l (standard error = 14.1 mg/l; range = 8.4 - 57.0 mg/l). Two of the non-residential RUCK systems, the service station and the shopping center, had greywater total nitrogen concentrations exceeding 30 mg/l. The high total nitrogen concentration at one, and possibly both, of these non-residential systems was due to a toilet connection to the greywater septic tank to supply more carbon for denitrification (Rusciani, 1990). For both Pinelands residential and non-residential RUCK systems, the average greywater nitrate- and nitrite-nitrogen concentration was 0.2 mg/l. Thus, the greywater total nitrogen was mostly in the Kjeldahl form.

The University of Rhode Island (URI) researchers also found greywater total nitrogen to be mostly TKN (Gold et al., 1990). The average greywater TKN concentrations for two Charlestown, Rhode Island RUCK systems monitored by URI were 16.4 and 27.1 mg/l and the average greywater TKN concentration for a replicated URI one-fifth scale RUCK evaluation was 17 mg/l (Gold et al., 1990). Except for the one URI system with high greywater TKN (27.1 mg/l), these values are comparable to those found in the Pinelands residential RUCK systems.

Beginning in July 1989, blackwater was sampled from five residential systems and three non-residential systems which had accessible blackwater septic tanks. Between two and four blackwater samples were collected from each of the eight systems. The blackwater was sampled to determine whether nitrogen was being removed from the sand filter by denitrification occurring in anaerobic microenvironments of the sand filter. Appreciable ammonia volatization, another possible nitrogen removal mechanism, occurs only at a pH greater than 8 (Gold et al., 1990), a higher pH than found in blackwater entering Pinelands sand filters (the average blackwater pH for the systems sampled was 7.3, range = 6.7 - 7.9).

The nitrogen in blackwater, like that in greywater, was found to be mostly in the Kjeldahl form. The average blackwater total nitrogen concentration for the five residential systems was 77.6 mg/l (standard error = 13.5 mg/l; range = 31.4 - 104.1 mg/l). The average filtered blackwater total nitrogen concentration for the five residential systems on the dates when the blackwater was collected was 89.1 mg/l (standard error = 9.2 mg/l; range = 67.0 - 119.6 mg/l). The average blackwater total nitrogen concentration for the three Pinelands non-residential RUCK systems was 75.0 mg/l (standard error = 5.5 mg/l; range = 64.4 - 82.7 mg/l). The average filtered blackwater total nitrogen concentration for the non-residential RUCK systems on the dates when blackwater was collected was 64.0 mg/l (standard error = 18.7 mg/l; range = 27.6 - 89.4 mg/l).

On many of the dates when both blackwater and filtered blackwater were sampled, the filtered blackwater actually had a higher total nitrogen concentration than the blackwater. This discrepancy may be caused by the sporadic nature of output from the households to the septic tanks producing slugs of differing total nitrogen concentrations throughout the system. Although other investigators (Loudon et al., 1985; Otis et al., 1975) have observed that some nitrogen can be removed from essentially aerobic environments such as those found in RUCK sand filters (Gold et al., 1990), because of the sporadic nature of the household output and the limited blackwater data obtained in this study, conclusions regarding the removal of nitrogen from the sand filter cannot be made.

The average blackwater total nitrogen concentrations for the Charlestown RUCK systems were greater than those for Pinelands RUCK systems. The average blackwater total nitrogen concentrations for the two Charlestown, Rhode Island RUCK systems monitored by URI were 251 mg/l (range = 149 - 346 mg/l) and 148 mg/l (range = 136 - 166 mg/l). The average filtered blackwater concentrations for the two Charlestown RUCK systems were 193 mg/l (range = 92 - 240 mg/l) and 113 mg/l (range = 89 - 151 mg/l) (Lamb, 1990).

IIIB. Estimation of Nitrogen Input

RUCK system nitrogen input will be defined as the nitrogen in the combined effluent of the blackwater and greywater septic tanks. The nitrogen in the combined septic tank effluent corresponds to the nitrogen concentration of conventional septic tank effluent. The nitrogen present in conventional septic tanks, like that present in the blackwater and greywater septic tanks of this study, is primarily in the form of TKN (Canter and Knox, 1985).

Several studies report total nitrogen concentrations of conventional septic tank effluent. The U.S. EPA (1980) reports a residential wastewater total nitrogen concentration range of 35-100 mg/l and Alhajjar (1989) reports a range of 10-134 mg/l with a mean of 73 mg/l and a median of 63 mg/l. Canter and Knox (1985) report a mean total nitrogen concentration of approximately 40 mg/l for medium strength household wastewater. Trela and Douglas (1979) report a mean septic effluent total nitrogen concentration of 43.1 mg/l and Brown (1980) reports a mean septic effluent total nitrogen concentration of 44.6 mg/l. Both the Trela and Douglas (1979) mean and the Brown (1980) mean are based upon reports by various investigators.

Nitrogen input to the RUCK systems studied could not be measured directly because a fraction of the nitrogen was lost through denitrification when the blackwater and greywater were combined in the pump tank or the rock tank. To directly calculate the actual amount of nitrogen entering RUCK systems through the blackwater and greywater wastestreams, greywater and blackwater flow measurements are needed. Because the installation of flow meters was not practical due to economic and technical reasons, a chloride mass balance approach was attempted in order to calculate greywater to blackwater flow ratios (the equation and assumptions are presented in Appendix 4). However, because all the assumptions did not hold true during the course of this study, the chloride mass balance method was abandoned and U.S. EPA (1980) flow ratio estimates were used.

According to the U.S. EPA (1980), when greywater represents all non-toilet wastes, the average greywater to blackwater flow ratio is approximately 60:40, and when greywater represents only the kitchen and laundry wastes, the average greywater to blackwater flow ratio is approximately 40:60. Although these ratios vary depending upon water usage and water-saving devices within the home, due to a lack of reliable data on home water usage, the Pinelands residential RUCK system greywater to blackwater flow was estimated using these exact ratios. For the ten households that were plumbed so that the greywater consisted of all non-toilet wastes, a 60:40 greywater to blackwater flow ratio was assigned. For the single household (system 4) that was plumbed so that the greywater consisted of only kitchen and laundry wastes, a 40:60 greywater to blackwater flow ratio was assigned. For the four remaining households at which the greywater plumbing was not determined, it was assumed that the greywater consisted of all non-toilet wastes and a 60:40 greywater to blackwater flow ratio was assigned.

The system nitrogen inputs were calculated using the assigned flow ratios, the filtered blackwater total nitrogen concentrations, the greywater total nitrogen concentrations, and the formula $N_i = (N_b + (R * N_g))/(1 + R)$ where N_i is the nitrogen input concentration (mg/l), R is the ratio of greywater flow to blackwater flow (for example 60:40 = 1.5), N_b is the filtered blackwater total nitrogen concentration (mg/l), and N_g is the greywater total nitrogen concentration (mg/l). See Table 1 for the calculated nitrogen inputs for the fifteen Pinelands residential RUCK systems.

The average estimated total nitrogen input for the fifteen Pinelands residential RUCK systems was 43.5 mg/l (standard error = 1.5 mg/l). This estimated input is comparable to that reported by Canter and Knox (1985), Trela and Douglas (1979), and Brown (1980).

IIIC. Total Nitrogen in Rock Tank Effluent and Total Nitrogen Removal Estimates

The "final effluent total nitrogen" (FETN) concentration is defined as the total nitrogen concentration in the rock tank effluent at the point of discharge to the drainfield. Table 2 presents the mean, minimum, maximum, range, and standard error of the FETN concentrations for each of the eighteen RUCK systems. The mean FETN concentrations ranged from 10.2 mg/l at system 1 to 52.6 mg/l at system 17. The distribution of FETN concentrations for the eighteen RUCK systems is presented in Figure 3.

The mean FETN concentration for the fifteen Pinelands residential RUCK systems was 19.9 mg/l (standard error = 2.1 mg/l). The median FETN concentration was 18.3 mg/l. A chi-square test of normality indicated that the mean was based on a normally distributed sample. The mean residential RUCK FETN concentration excluding the two poorly functioning residential systems (systems 8 and 13) was 17.2 mg/l (standard error = 1.1 mg/l).

The mean FETN for the three Pinelands non-residential systems was 42.7 mg/l (standard error = 7.6 mg/l), approximately double that of the residential systems. Two of the non-residential systems had higher mean FETN concentrations than any of the residential systems and the third non-residential system had a higher mean FETN concentration than all but two of the residential systems.

The mean FETN concentrations for the Charlestown, Rhode Island RUCK systems monitored by URI were greater than the mean for the Pinelands residential RUCK systems. The mean FETN concentrations for the two Charlestown systems were 30.5 mg/l (standard error = 1.9 mg/l) and 53.3 mg/l (standard error = 4.0 mg/l), respectively. The mean FETN concentration for the URI one-fifth scale replicated study was comparable to the Pinelands mean FETN. The mean FETN concentration for the one-fifth scale system was 23 mg/l (standard error = 1.4 mg/l) when greywater represented 25% of the total wastewater flow and 18 mg/l (standard error = 1.3 mg/l) when greywater represented 40% of the total wastewater flow (Gold et al., 1990).

Table 1. Total nitrogen input estimates for Pinelands residential RUCK systems calculated from U.S. EPA (1980) flow ratios. Flow ratios are based on assumed plumbing routes for systems 1, 2, 10, and 11. The calculated TN input for system 10 is based on limited TN data due to a malfunctioning pump.

System #	Adopted GW:BW Flow Ratio	Calculated TN Input (mg/l)
1	60%:40%	30.3
2	60%:40%	48.6
3	60%:40%	42.2
4	40%:60%	47.8
5	60%:40%	47.0
6	60%:40%	38.4
7	60%:40%	35.4
8	60%:40%	44.8
10	60%:40%	51.1
11	60%:40%	43.4
12	60%:40%	51.9
13	60%:40%	43.0
14	60%:40%	40.5
15	60%:40%	45.9
16	60%:40%	42.0
		Average TN input: 43.5 (S.E. = 1.5)

Table 2. Final effluent total nitrogen data for the 18 monitored RUCK systems. For system 1, three sampling dates were excluded due to an installation error. System 9, 17, and 18 are non-residential systems. System 10 was not sampled on five of the twelve sampling dates due to a malfunctioning pump. The seven sampling dates following the correction of switched pipes are included for system 14.

Final Effluent Total Nitrogen, mg/l

System #	n	min	max	range	mean	std err
1	9	2.9	16.4	13.5	10.2	1.4
2	12	8.9	56.0	47.1	17.6	3.7
3	13	11.5	26.0	14.5	16.9	1.2
4	13	11.0	48.0	37.0	22.0	3.0
5	12	8.6	21.0	12.4	13.2	1.0
6	12	9.4	27.0	17.6	15.0	1.4
7	13	10.0	23.0	13.0	15.6	1.1
8	12	20.0	52.0	32.0	33.8	2.9
9	12	5.8	44.1	38.3	27.9	4.0
10	7	8.4	34.0	25.6	18.4	3.5
11	12	11.5	42.0	30.5	23.8	2.5
12	13	8.7	30.0	21.3	15.6	1.6
13	12	15.5	56.0	40.5	40.7	3.7
14	7	7.4	18.1	10.7	13.1	1.6
15	12	7.0	25.0	18.0	18.1	1.8
16	12	13.0	40.0	27.0	23.9	2.6
17	7	29.0	100.0	71.0	52.6	9.5
18	8	24.5	76.0	51.5	47.7	6.6
Grand mean					23.7	2.9
residential system mean					19.9	2.1
non-residential system mean					42.7	7.6

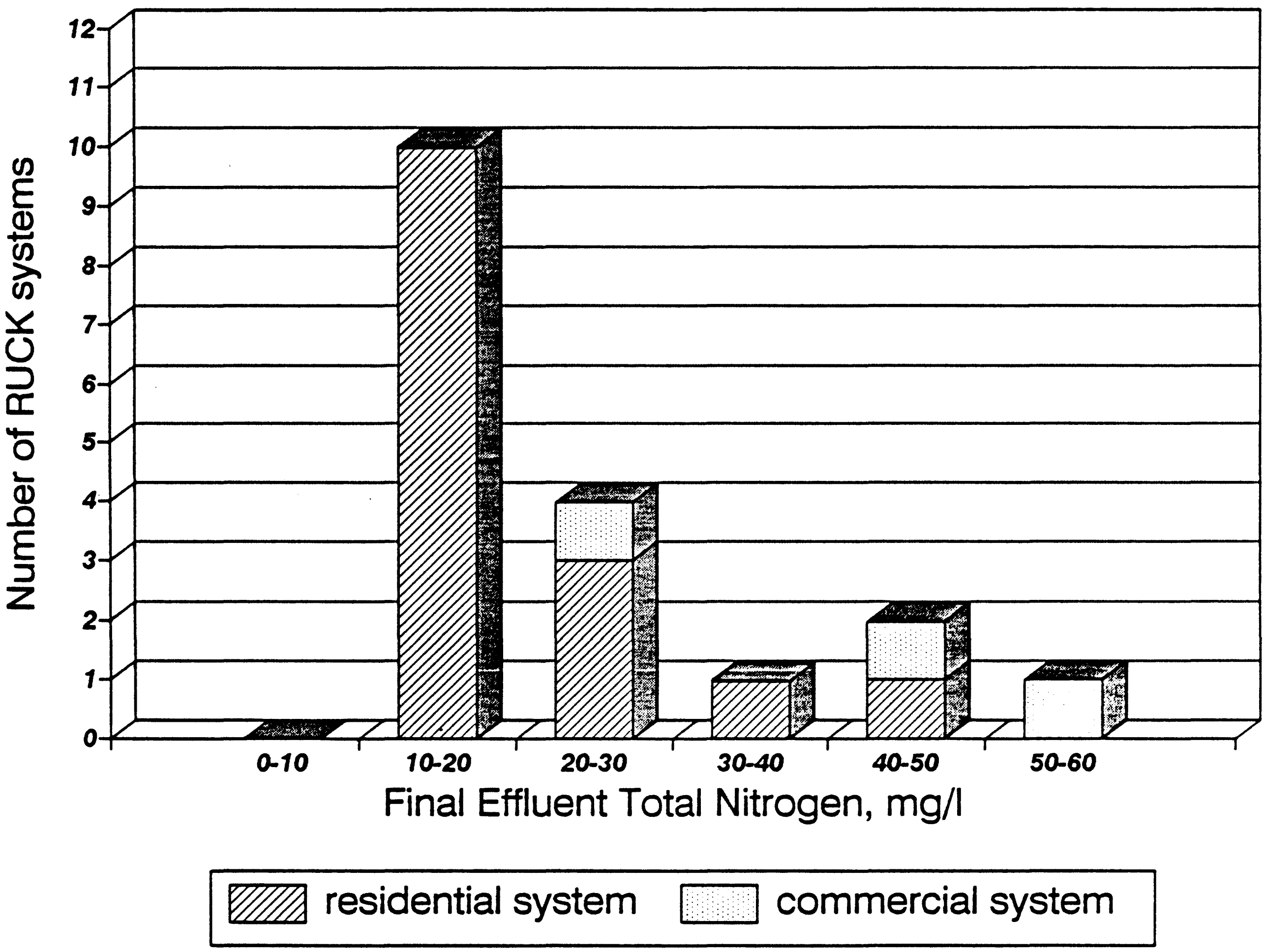


Figure 3. The distribution of average final effluent total nitrogen concentrations for the monitored Pinelands RUCK systems.

To allow for comparisons with conventional septic systems, total nitrogen removal efficiency will be described as the percent nitrogen removed between, but not including, the septic tanks and drainfield. Thus, the nitrogen removal reported for the Pinelands RUCK systems is calculated as the percent difference between the septic tank effluent average estimated TN concentration (average TN input = 43.5 mg/l), and the rock tank effluent average TN concentration (average TN output = 19.9 mg/l).

Table 3 presents the calculated total nitrogen input estimates (from Section IIIC and Table 1), the measured rock tank effluent total nitrogen (FETN), and the calculated total nitrogen removal estimates for each of the fifteen Pinelands residential RUCK systems. Removal efficiency could not be determined for the non-residential systems due to the lack of greywater:blackwater flow ratio information for these systems. The estimated total nitrogen removal for the fifteen residential RUCK systems ranged from 5% (system 13) to 72% (system 5). The average estimated total nitrogen removal for the residential RUCK systems was 54%.

One of the Charlestown RUCK systems had an average percent total nitrogen removal equal to the average estimated removal for the Pinelands residential systems. The second Charlestown RUCK system had an average percent total nitrogen removal that was less than that of all but one of the Pinelands residential systems. The average TN removal for the Charlestown systems was 54% (standard error = 2.6%) and 29% (standard error = 5.9%), respectively (Gold et al., 1990).

Although the majority of the RUCK systems installed in the Pinelands successfully removed nitrogen from the wastewater, nitrogen removal was less than the 65% originally assumed at the initiation of the study. This appeared to be a function of one or more of the following factors: 1. incomplete nitrification in the sand filter which introduced TKN into the rock tank; 2. elevated TKN concentrations in the greywater; and 3. incomplete denitrification in the rock tank. These factors, their frequency of occurrence, and factors that limit them are discussed in the following section.

IIID. Factors Affecting Final (Rock Tank) Effluent Nitrogen Concentrations

IIID1. Nitrification

Nitrification is the oxidative conversion of ammonium (NH_4^+) to nitrate (NO_3^-). The RUCK system's vented sand filter is designed to provide the aerobic environment needed for nitrification to occur. Because the denitrification process only acts on the nitrate form of nitrogen, the nitrification process must occur

Table 3. Total nitrogen removal efficiency estimates for Pinelands residential RUCK systems. Total nitrogen inputs were calculated from U.S. EPA (1980) flow ratios (see Table 1) and the average total nitrogen removal was calculated as the percent difference between the average TN output and the average TN input. The calculated TN input for system 10 is based on limited data due to a malfunctioning pump.

System #	Calculated TN Input (mg/l)	Mean FETN (mg/l)	Estimated TN Removal (%)
1	30.3	10.2	66%
2	48.6	17.6	64%
3	42.2	16.9	60%
4	47.8	22.0	54%
5	47.0	13.2	72%
6	38.4	15.0	61%
7	35.4	15.6	56%
8	44.8	33.8	25%
10	51.1	18.4	64%
11	43.4	23.8	45%
12	51.9	15.6	70%
13	43.0	40.7	5%
14	40.5	13.1	68%
15	45.9	18.1	61%
16	42.0	23.9	43%
	Average TN input: 43.5	Average TN output: 19.9	Average TN removal: 54% (S.E.=4.7%)

before nitrogen can be converted to nitrogen gas by denitrification. Thus, incomplete nitrification may limit the nitrogen removal ability of the RUCK system.

There is a significant correlation between sand filter nitrification and rock tank effluent nitrogen (FETN) concentrations ($r_{.01,13df} = -.938$). This relationship is shown graphically in Figure 4. Graphs showing sand filter nitrification and final effluent total nitrogen concentration for each of the eighteen monitored systems are presented in Appendix 5.

Sand filter nitrification was calculated as the percentage of total nitrogen in the sand filter effluent present as nitrate. Table 4 presents the mean, minimum, and maximum nitrification rate for each of the eighteen RUCK systems. The mean sand filter nitrification for the fifteen Pinelands residential RUCK systems was 57% (standard error = 5.2%; range = 7% - 80%). If the two poorly functioning residential systems (systems 8 and 13) are excluded, the mean sand filter nitrification is 64% (standard error = 2.8%). The mean sand filter nitrification for the three Pinelands non-residential systems was 64% (standard error = 8.4%; range = 51% - 80%).

For comparison with the Pinelands residential systems, the mean sand filter nitrification for the two Charlestown, Rhode Island RUCK systems monitored by URI were 58% (standard error = 1.6%) and 57% (standard error = 2.4%), respectively. Sand filters studied in URI's one-fifth scale replicated study had an average nitrification of 69% (standard error = 0.9%; range = 46 - 80%) (Gold et al., 1990).

The distribution of Pinelands RUCK system nitrification rates is presented in Figure 5. Most systems, including the three non-residential systems, had average nitrification rates greater than 50%. Only three Pinelands RUCK systems had average nitrification rates of less than 50%. Nitrification rates of less than 50% reflect inadequate nitrogen removal which may be due to problems with sand filter installation or design.

The nitrogen levels (divided into TKN and NO_2+NO_3) at each sampling point (for example, the pump tank) for a system with poor nitrification (system 13) and a system with good nitrification (system 6) are compared in Figure 6. It can be seen that system 13 has a lower percentage of filtered blackwater (FBW) NO_2+NO_3-N and a higher final effluent (FE) total nitrogen concentration than system 6.

Factors that may influence nitrification rates and, thus, the RUCK system's ability to remove nitrogen, include sand filter temperature, sand filter pH (and alkalinity), and the oxygen concentration in the sand filter. Low sand filter oxygen concentrations may have caused poor nitrification rates at two Pinelands

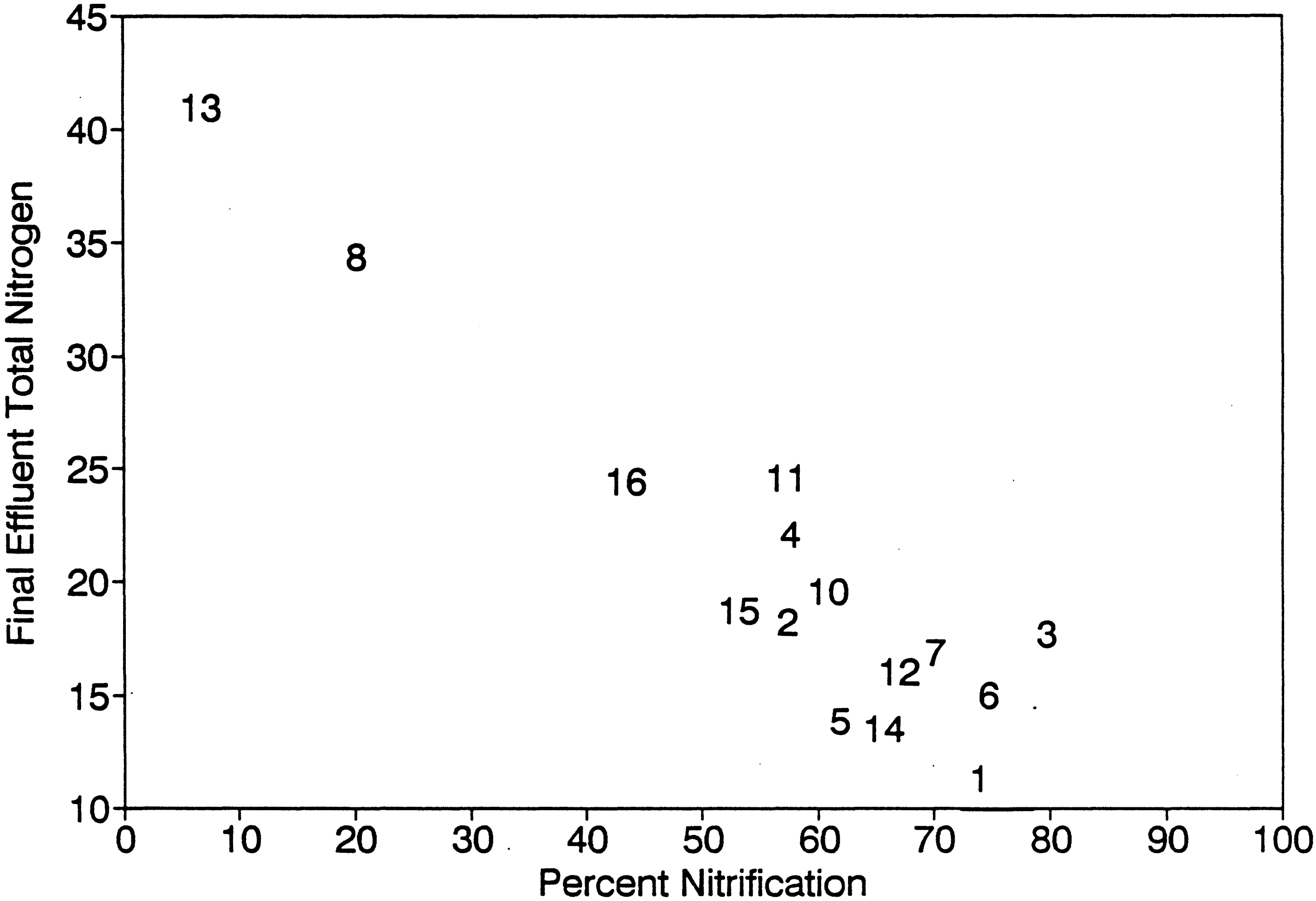


Figure 4. The relationship between final effluent total nitrogen (FETN) concentration and sand filter nitrification averages for the Pinelands residential RUCK systems ($r_{.01,\ 13df} = -.938$). The numbers graphed are the designated system numbers.

Table 4. Sand filter nitrification data for the 18 monitored RUCK systems. Nitrification was calculated as the percentage of NO2+NO3 in the filtered blackwater total nitrogen. For system 1, three dates were excluded due to an installation error. System 9, 17, and 18 are non-residential systems. System 10 was not sampled on five sampling dates due to a malfunctioning pump. The seven sampling dates following the correction of switched pipes are included for system 14.

Sand Filter Nitrification, %

System #	n	min	max	mean	std err
1	10	31.6	100.0	75.2	6.1
2	11	18.6	81.9	58.9	5.5
3	12	53.0	94.8	80.1	3.5
4	12	8.5	80.4	58.6	5.6
5	12	25.9	85.7	63.9	5.8
6	12	54.2	90.2	75.4	3.2
7	12	38.0	83.9	71.2	3.8
8	12	0.0	48.6	20.8	4.7
9	13	0.4	83.0	50.9	8.4
10	3	42.5	76.0	60.4	9.9
11	13	26.5	76.3	57.3	4.6
12	13	51.0	84.5	67.7	3.5
13	10	0.1	20.7	7.3	2.3
14	7	13.3	86.4	66.0	9.1
15	11	13.9	98.5	55.7	7.5
16	11	0.6	82.3	43.2	9.1
17	5	30.3	77.6	60.2	8.0
18	8	49.4	93.5	79.5	4.7
Grand mean				58.5	4.5
residential system mean				57.4	5.2
non-residential system mean				63.5	8.4

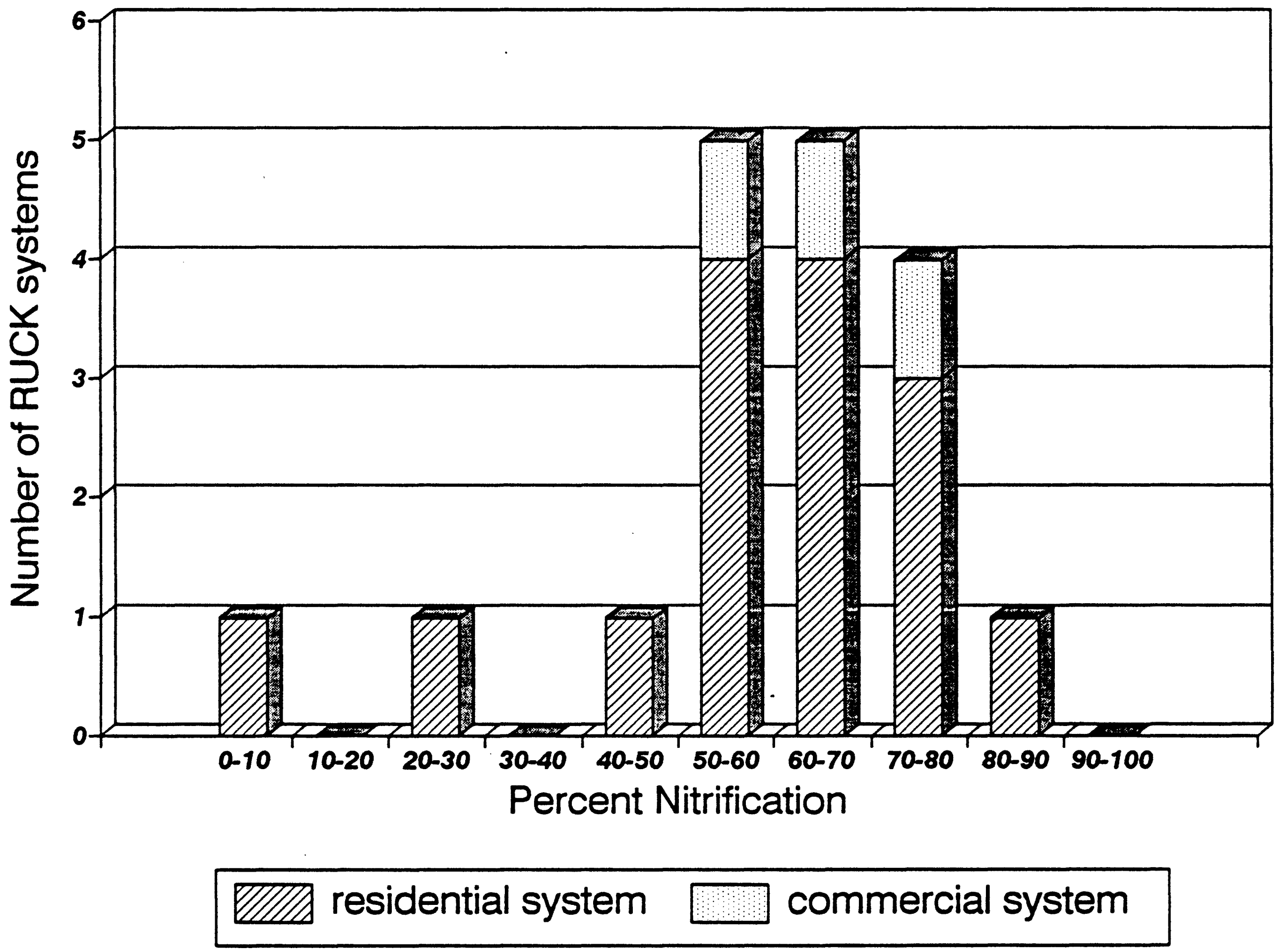
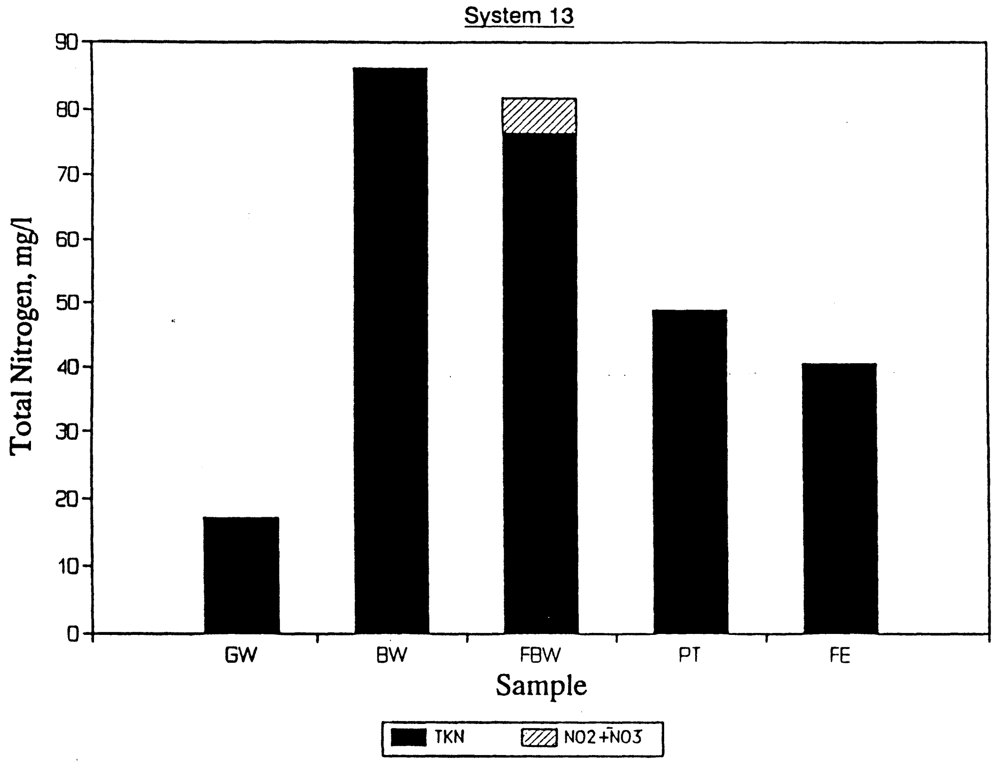


Figure 5. The distribution of average sand filter nitrification rates for the monitored Pinelands RUCK systems.



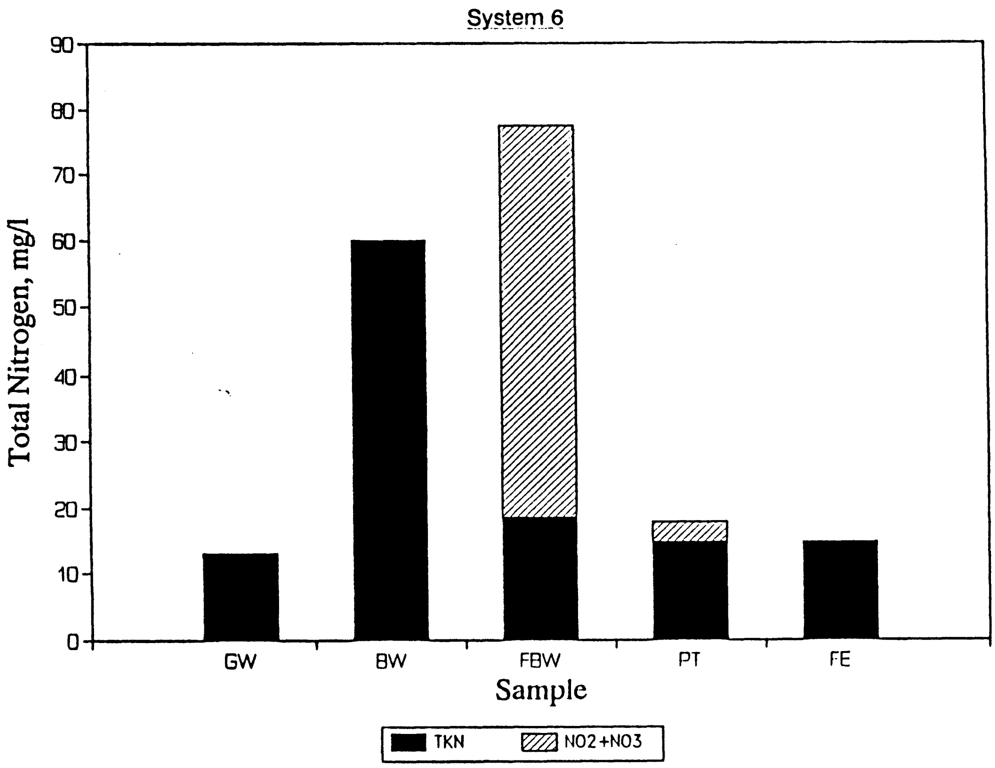


Figure 6. A comparison of average nitrogen levels at each sampling point for a RUCK system with poor nitrification (system 13) and a RUCK system with good nitrification (system 6). The sampling points are the greywater tank (GW), the blackwater tank (BW), the filtered blackwater port (FBW), the pump tank (PT), and the rock tank also referred to as final effluent (FE). The total nitrogen concentration is divided into total Kjeldahl nitrogen (TKN) and NO_2+NO_3.

RUCK systems (systems 13 and 16) which had their sand filter vent pipes moved from the design-specified position. The vents at these systems were moved from directly over the sand filter to a position near the house. Relocated vent pipes could result in decreased nitrification rates by preventing an adequate amount of oxygen from reaching the sand filter due to: 1. improper installation of the vent pipes during relocation; 2. placement of the vent pipes in a wind-protected area such as near the wall of the house; or 3. the increased distance that oxygen has to travel between the vent opening and the sand filter. Barring possible effects of vent position and snow cover, vent pipe heights of between 0 (flush to the ground) and 31 inches did not appear to affect nitrification rates.

Alkalinity and pH may affect sand filter performance because nitrification, which produces hydrogen (H^+) ions, may also be limited by low pH. For every milligram of NH_4^+ oxidized by nitrification, approximately 7.14 milligrams of HCO_3^- alkalinity is required to neutralize the H^+ produced. If sufficient alkalinity is not available to neutralize the H^+ produced, the pH of the sand filter could drop below 5.5 and nitrification could be inhibited (Gold et al., 1990). Alkalinity was not measured during the Pinelands RUCK study; however, during the URI one-fifth scale replicated study, there was an absence of alkalinity in the sand filter on all but three sampling dates. The average sand filter pH of 4.0 may have been partially responsible for the lack of complete nitrification observed in URI's one-fifth scale study (Gold et al., 1990). Alkalinity or pH did not appear to be limiting factors to sand filter nitrification in URI's Charlestown RUCK study. Sand filter pH ranged from 5.2 to 7.4 at one Charlestown system and from 4.6 to 6.8 at the other system. The pH rarely dropped below 5.5 (Gold et al., 1990).

The average blackwater pH, the pH at the inlet of the sand filter, for the Pinelands systems at which blackwater was sampled was 7.3 (range = 6.7 - 7.9) and the average filtered blackwater pH (the pH at the outlet of the sand filter) was 4.1 (range = 3.9 - 7.0) for the Pinelands RUCK systems. Thus, the pH in Pinelands sand filters decreased between the sand filter inlet and the sand filter outlet due to the production of H^+ ions by nitrification.

The near neutral pH entering the Pinelands sand filters, pH 7.3 compared to pH 8.1 and 8.4 at URI (Gold et al., 1990), suggests that water entering Pinelands sand filters may have relatively low alkalinity due to the acidity of Pinelands water. Also, the decrease in sand filter pH between the sand filter inlet and outlet and the low pH of filtered blackwater in most of the monitored Pinelands systems (Figure 7), suggests a possible depletion of alkalinity. If the alkalinity is, in fact, being depleted in Pinelands sand filters, the subsequent decrease in pH may be limiting nitrification.

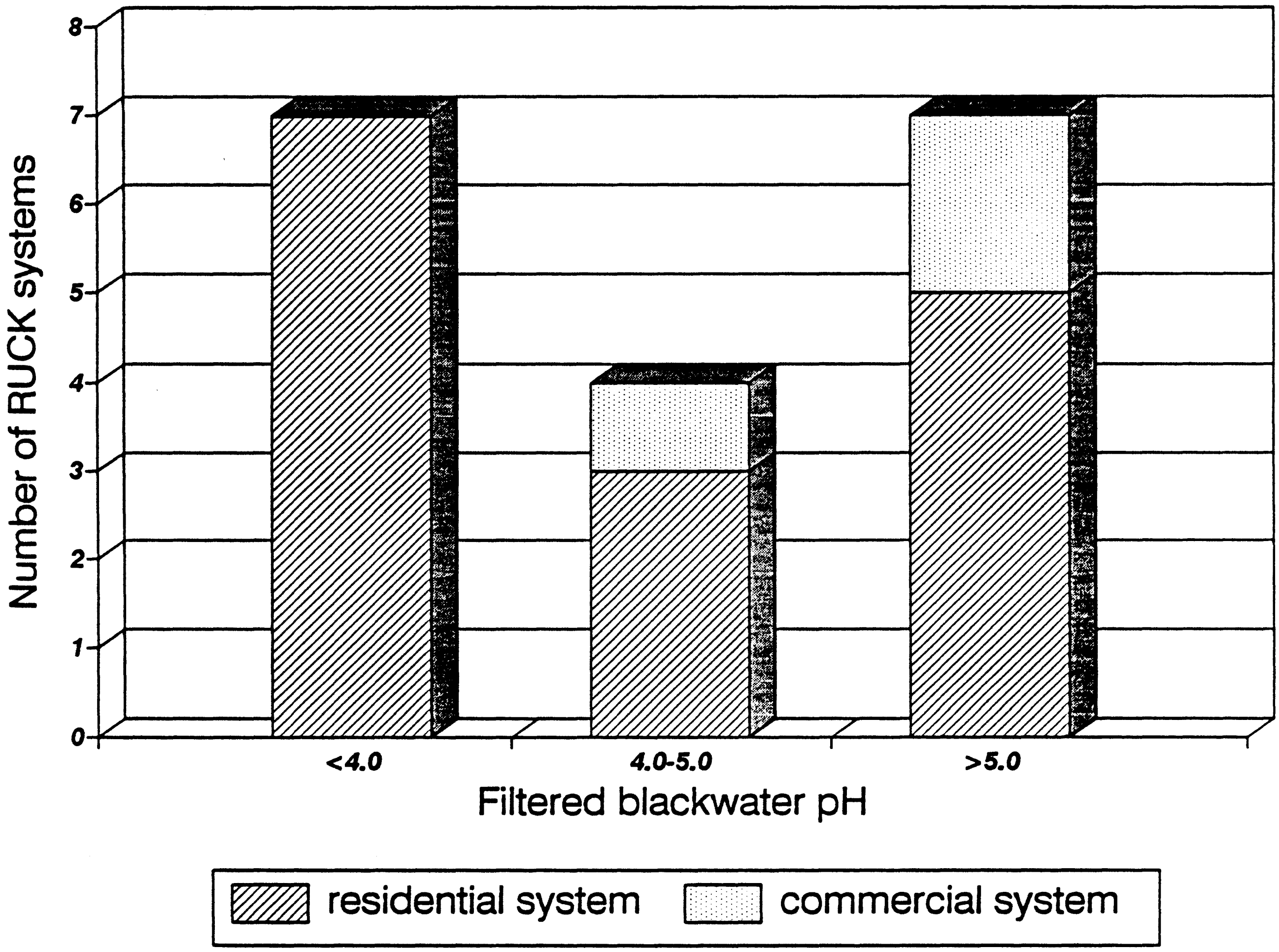


Figure 7. The distribution of average filtered blackwater pH values for the monitored Pinelands RUCK systems.

Other researchers have shown pH's less than 5.5 to inhibit nitrification (Haug and McCarty, 1972). Figure 8 shows nitrification to be negatively, instead of positively, correlated with pH ($r_{.01,13df} = -.724$). This apparent contradiction is observed because the nitrification process lowers the sand filter pH. To determine whether the nitrification rate at the Pinelands RUCK systems is limited by low alkalinity and to reach significant conclusions on the effects of pH and alkalinity on sand filter nitrification would require further study.

Temperatures below 10-15 degrees Celsius can significantly impact nitrification rates (McCarty et al., 1969; Dawson and Murphy, 1972; Stanford, et al., 1975; Focht and Chang, 1975; Stanier and Adelberg, 1976; in Gold et al., 1990). Because RUCK sand filters are underground they are not exposed to outside temperature extremes. However, the temperature of Pinelands RUCK system sand filter effluent fell below 15 degrees Celsius on some dates between the months of October and May and below 10 degrees Celsius on some dates during the winter months of December through March. In URI's Charlestown, Rhode Island RUCK system study, nitrification rates did not appear to be markedly influenced by winter temperatures (Gold et al., 1990). However, in URI's one-fifth scale replicated study, nitrification rates did decrease slightly with decreased temperatures (Gold et al., 1990).

In the Pinelands study, there was a significant relationship ($r_{.01,90df} = .275$) between sand filter temperatures and nitrification rates (Figure 9) when systems 8, 13, and 16, systems with consistently poor nitrification rates, were excluded. Individually, ten of the eighteen Pinelands systems (systems 1, 3, 4, 5, 6, 7, 11, 12, 14, and 15) had nitrification rates which appeared to be temperature related on many of the sampling dates. Seasonal nitrification trends were especially obvious for systems 11 and 12. The nitrification rates at systems 8, 13, 16, and at the three non-residential systems appeared to be more strongly influenced by factors other than temperature. Whether a relationship existed between temperature and nitrification for system 2 could not be determined due to too few data points, and filtered blackwater temperature was not measured at system 10 due to a malfunctioning pump. Graphs of sand filter temperature and sand filter nitrification by sample date for each system are presented in Appendix 6.

IIID2. Denitrification

Denitrifying bacteria, which reduce nitrate (NO_3^-) to nitrogen gas, depend on an anaerobic environment and an adequate carbon source. The RUCK system rock tank, and, if present, the pump tank prior to the rock tank, provide an anaerobic environment for

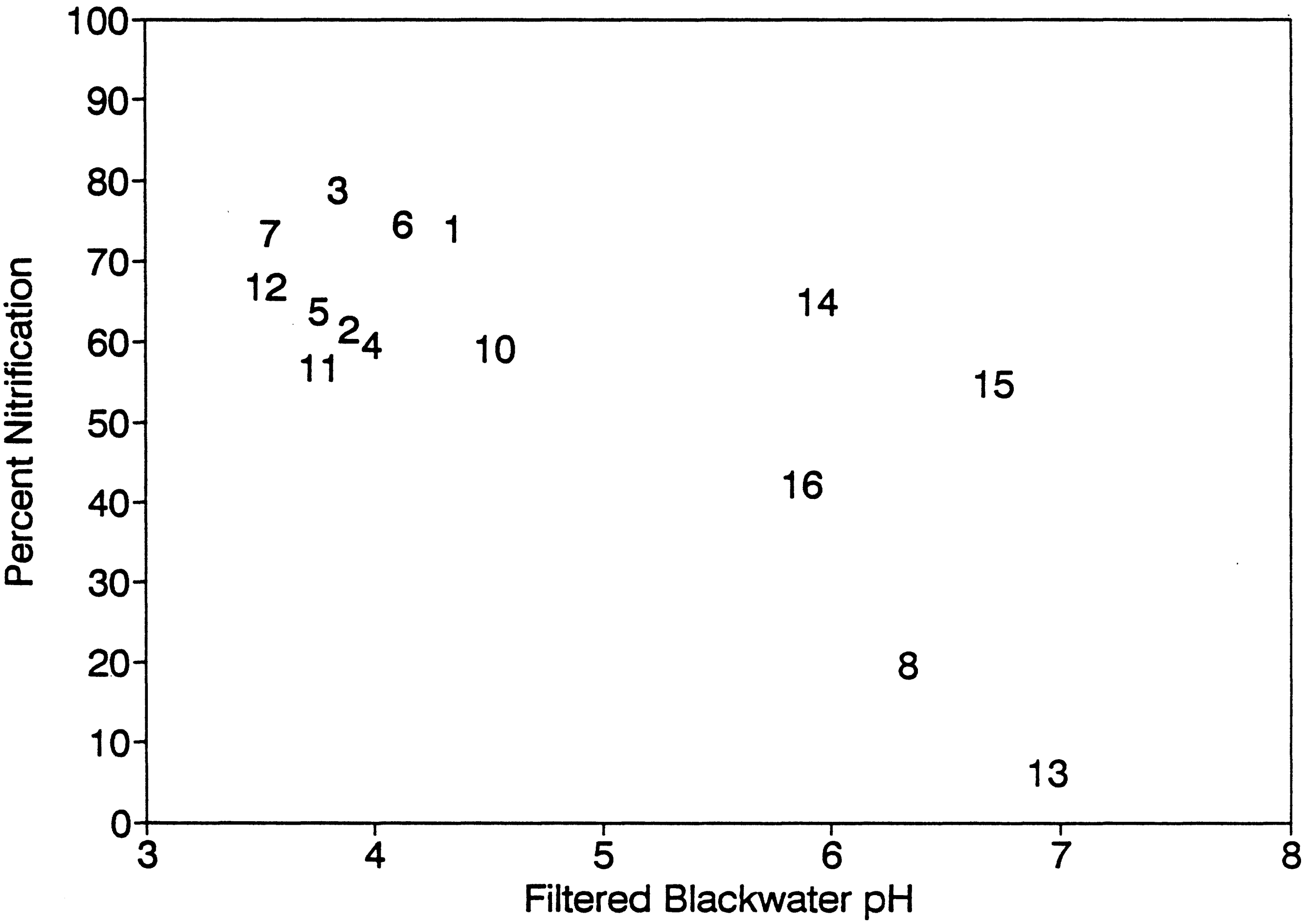


Figure 8. The relationship between sand filter nitrification and filtered blackwater pH averages for the Pinelands residential RUCK systems ($r_{.01, 13df} = -.724$). The numbers graphed are the designated system numbers.

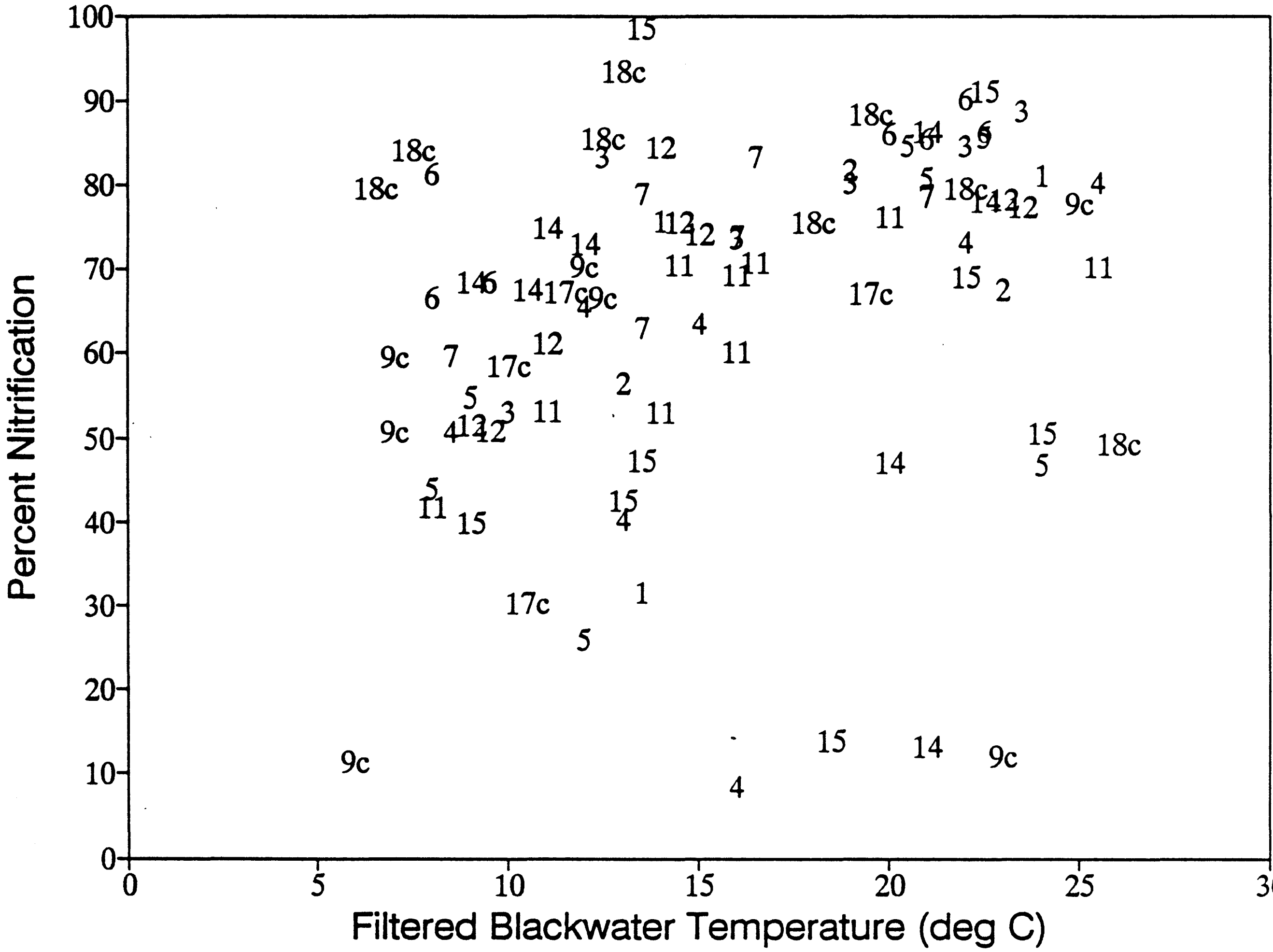


Figure 9. The relationship between sand filter nitrification and filtered blackwater temperature on individual sample dates for the monitored Pinelands RUCK systems (excluding systems 8, 13, and 16). The numbers graphed are the designated system numbers (a "c" following the number indicates that the system services a commercial unit).

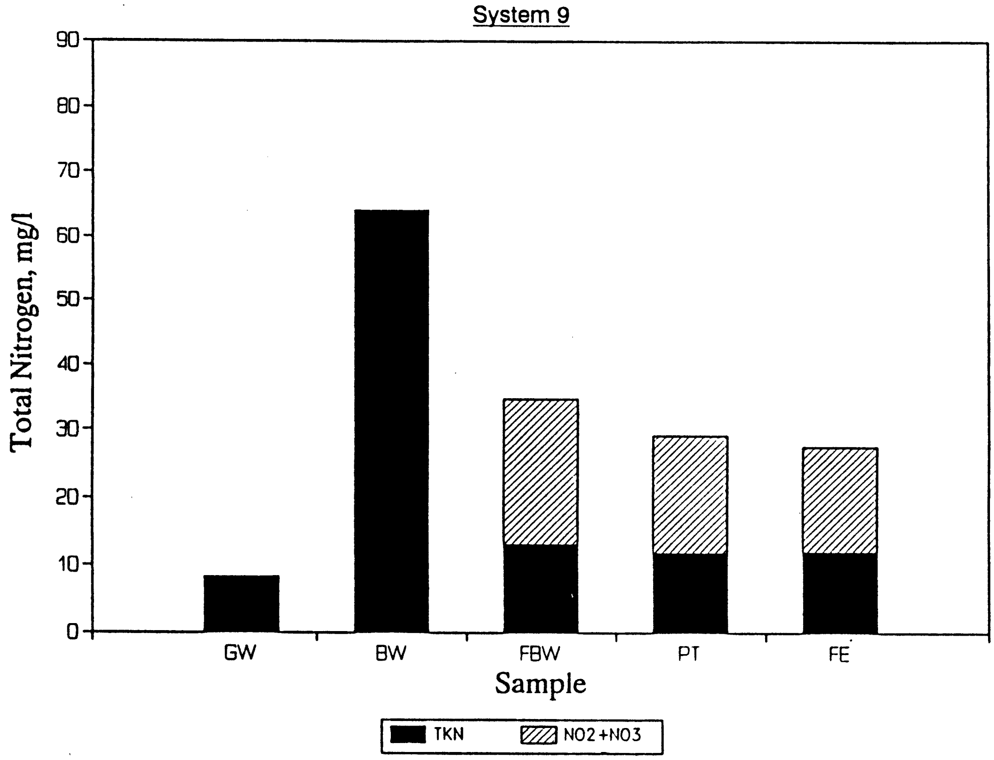
denitrification. The greywater, which mixes with the filtered blackwater in the pump tank or the rock tank, provides the carbon source.

Because denitrifying bacteria cannot convert total Kjeldahl nitrogen (TKN = ammonium + organic nitrogen), the predominant form of nitrogen entering the system, to nitrogen gas, nitrification must occur prior to denitrification. Thus, a large amount of nitrate remaining in rock tank effluent is an indication that a low denitrification rate is limiting nitrogen removal.

Denitrification was calculated as the percentage decrease in nitrate between pump tank influent (or, in the absence of a pump tank, rock tank influent) and rock tank effluent. For seventeen of the eighteen monitored Pinelands RUCK systems, the denitrification rate was consistently greater than 90%. These seventeen RUCK systems had rock tank effluent average nitrate concentrations of between 0 mg/l and 1.1 mg/l. Eleven of the seventeen systems consistently had no nitrate remaining in the rock tank effluent and, thus, denitrification rates of 100%. One of the Pinelands non-residential RUCK systems (system 9) had much lower denitrification rates. This system, which serviced a doctors office, had an average of 15.8 mg/l nitrate remaining in the rock tank effluent and an average denitrification rate of only 9%.

One of the Charlestown RUCK systems monitored by URI, like eleven of the Pinelands systems, consistently had denitrification rates of 100%. The second Charlestown system had an average denitrification rate of 62% (standard error = 9.0%) with a range of 28-100% (Gold et al., 1990).

Figure 10 compares the nitrogen levels (divided into TKN and NO_2+NO_3) at each sample port for system 9, the doctors office system with poor denitrification, and system 6, a residential system with 100% denitrification. It can be seen that both systems had a large percentage of their filtered blackwater (FBW) total nitrogen in the NO_2+NO_3 form, indicating that both systems had a good (high) nitrification rate. It can also be seen that systems 6 and 9 differed in the amount of NO_2+NO_3 that remained in their pump tank (PT) and their rock tank final effluent (FE). System 9 had a large percentage of the filtered blackwater nitrate remaining in the pump tank and the final effluent whereas system 6 had very little nitrate remaining in the pump tank and no nitrate remaining in the final effluent. Thus, system 6 had a much lower final effluent total nitrogen concentration when compared to system 9 due to an adequate rate of denitrification at system 6 which converted the pump tank and rock tank nitrate to nitrogen gas which was dissipated from the system.



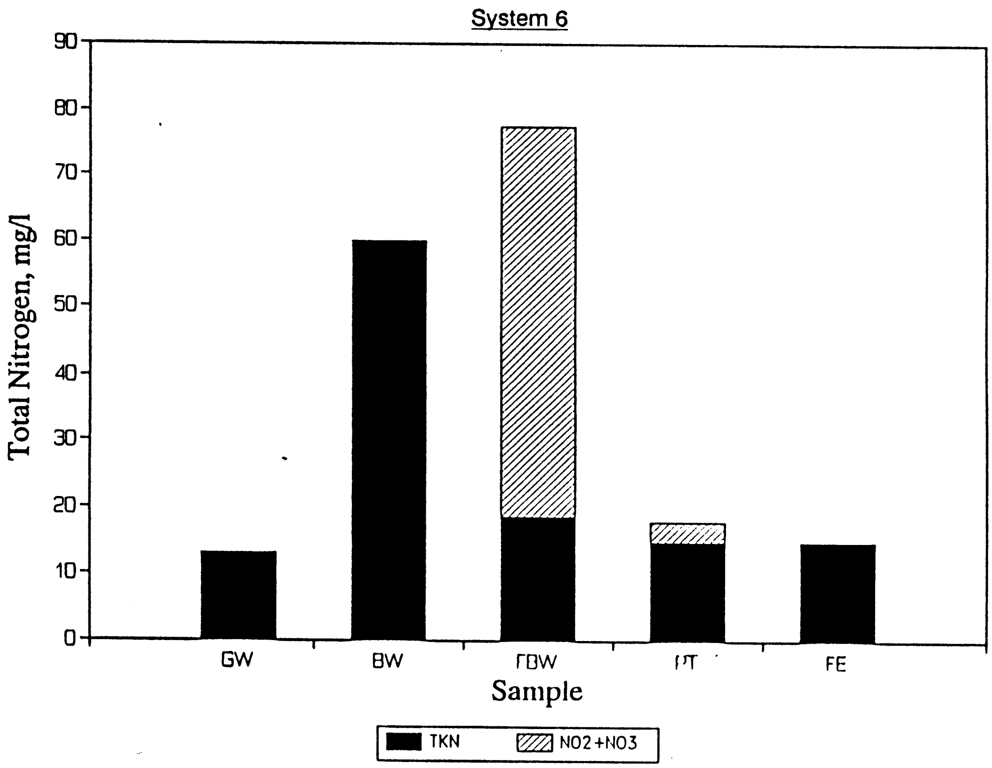


Figure 10. A comparison of average nitrogen levels at each sampling point for a RUCK system with poor denitrification (system 9) and a RUCK system with good denitrification (system 6). The sampling points are the greywater tank (GW), the blackwater tank (BW), the filtered blackwater port (FBW), the pump tank (PT), and the rock tank also referred to as final effluent (FE). The total nitrogen concentration is divided into total Kjeldahl nitrogen (TKN) and NO_2+NO_3.

A possible reason for the low denitrification rate at the Pinelands doctors office (system 9) is lack of an adequate carbon supply in the greywater. At residential systems, much of the greywater carbon is supplied by washwater. Besides the obvious lack of showers, a washing machine, or kitchen sink at the doctors office, the clarity of the greywater samples (greywater normally has a cloudy grey appearance) also supported the possibility that this system lacked an adequate carbon supply. Total organic carbon (TOC) analyses performed by the University of Rhode Island on a limited number of Pinelands RUCK greywater samples provided further evidence that the system 9 greywater was low in carbon. The greywater TOC concentration at system 9 was 64 mg/l on one sample date and 15 mg/l on the second date compared to an average TOC concentration of 103 mg/l (standard error = 10.8) for the remaining fourteen residential and non-residential Pinelands systems which had greywater collected for TOC analysis. The other Pinelands non-residential RUCK systems appeared to have an adequate amount of greywater carbon supplied by restaurant dishwashing and possibly a toilet attached to the greywater system (system 17) and a toilet attached to the greywater system (system 18).

Even though an inadequate greywater carbon source appeared to cause the poor denitrification rate at system 9, three of the Pinelands residential RUCK systems had greywater carbon concentrations as low or lower than those at system 9 while retaining a high rate of denitrification. These systems most likely had a greater amount of TOC than that estimated by the limited TOC data due to either a greater volume of greywater than estimated or the sampling of greywater slugs having low TOC.

Besides the possibility that low denitrification may be caused by an inadequate amount of carbon in the greywater, the rate of denitrification may also be influenced by the rock tank carbon-to-nitrate ratio, the make-up of residential greywater (bathroom washwater, kitchen washwater, and laundry washwater), and the temperature of the rock tank wastewater (Gold et al., 1990).

The URI researchers found a wide variability in rock tank carbon-to-nitrate ratios which were not necessarily related to denitrification rates (Gold et al., 1990). Because of the limited Pinelands RUCK system carbon (TOC) data and the lack of greywater-to-blackwater flow data, no conclusions could be made concerning the effect of the carbon-to-nitrate ratio on the denitrification rate for the Pinelands RUCK systems.

Only one of the fifteen monitored Pinelands residential RUCK systems (system 4) was known to be plumbed so the greywater consisted of only kitchen and laundry wastes. One of the two Charlestown, Rhode Island systems was also plumbed in this manner.

The Charlestown system did not show consistent denitrification (Gold et al., 1990), however, the Pinelands system had a denitrification rate of 100%.

Based on limited data, the URI researchers found that the Charlestown system with the 62% average denitrification rate had lower denitrification rates during the winter months. No seasonal denitrification trends were observed for the Charlestown system which had 100% denitrification on all sample dates. Likewise, no seasonal denitrification trends were observed for any of the eighteen Pinelands RUCK systems, most of which had 90% to 100% denitrification in all seasons.

Although the reasons for low denitrification were not entirely clear, the poor denitrification rate at system 9 demonstrated that low denitrification produces an elevated rock tank final effluent total nitrogen (FETN) concentration. However, because only one of the Pinelands systems exhibited poor denitrification and because other factors, such as nitrification and TKN in the greywater, affected the FETN concentration of other Pinelands systems, denitrification rates were not correlated with the FETN concentrations. Therefore, denitrification did not appear to be an overall limiting factor affecting the nitrogen removal in Pinelands RUCK systems.

IIID3. Additional Factors that May Affect Final Effluent Nitrogen Concentrations

IIID3a. Greywater TKN Concentration

The greywater's Kjeldahl nitrogen, the main form of nitrogen in greywater, is not treated by the RUCK system because the greywater must by-pass sand filter nitrification in order to conserve carbon for denitrification. By missing the nitrification process, the greywater TKN is not converted to nitrate, and, thus, it is not converted to nitrogen gas by denitrification. Therefore, the greywater TKN concentration directly influences the TKN concentration in the rock tank. The amount of TKN supplied by the greywater to the rock tank depends on the concentration of TKN in the greywater and the percentage of greywater to blackwater flow.

By using the U.S. EPA (1980) estimated flow ratios and the average greywater TKN concentrations, it was determined that the residential systems' greywater TKN provided an average of 7.7 mg/l (standard error = 0.58, range = 4.6 - 12.7) of the 19.9 mg/l average residential system rock tank effluent total nitrogen. An average of 13 to 16 mg/l of the Charlestown RUCK systems' rock tank total nitrogen concentration was provided by the TKN present in the greywater (Gold et al., 1990).

Figure 11 presents the distribution of Pinelands RUCK system greywater total nitrogen concentrations. Most systems had greywater total nitrogen concentrations of less than 20 mg/l. Three systems, including two non-residential systems, had greywater total nitrogen concentrations of between 20 mg/l and 60 mg/l which functioned to significantly increase rock tank effluent nitrogen concentrations. High concentrations of TKN in RUCK system greywater can be caused by the connection of toilets to the greywater septic tank due to improper installation or to provide additional carbon for denitrification. The disposal of ammonia-based cleaners and other nitrogen containing substances into the washwater can also produce a high greywater TKN concentration.

Even though high concentrations of total nitrogen in the greywater was found to significantly contribute to high concentrations of total nitrogen in the rock tank, Pinelands RUCK system greywater total nitrogen concentrations were not correlated with corresponding final effluent total nitrogen concentrations. The reason for the lack of correlation is that nitrification, instead of the greywater total nitrogen concentration, limited the performance of most of the Pinelands systems.

Figure 12 presents the nitrogen levels (divided into TKN and NO_2+NO_3) at each sample point for a system with a high greywater total nitrogen concentration (system 18) and a system with a low greywater total nitrogen concentration (system 6). Both of these systems had a high nitrification rate (a large percentage of the FBW was in the NO_2+NO_3 form) and a high denitrification rate (the NO_3 present in the FBW had been dissipated as nitrogen gas in the pump tank and/or the rock tank). These systems differ due to the greater total nitrogen concentration in the final effluent at system 18 caused by the greater TKN concentration in the greywater.

IIID3b. Household Size

The number of people residing in the households and the concentration of total nitrogen entering the systems were evaluated to determine whether they had an effect on RUCK system rock tank effluent total nitrogen concentrations. Residential nitrogen inputs were estimated as between 30 and 52 mg/l, and between one and six persons resided in the Pinelands households. Neither the number of people in the households nor the total nitrogen concentration entering the systems were correlated with the rock tank effluent total nitrogen concentrations. A relationship between nitrogen input and output would be expected only if the RUCK systems did not remove any nitrogen, removed the same percentage of nitrogen from each system, or if the nitrogen removal ability was in some way determined or limited by the nitrogen concentration entering the system.

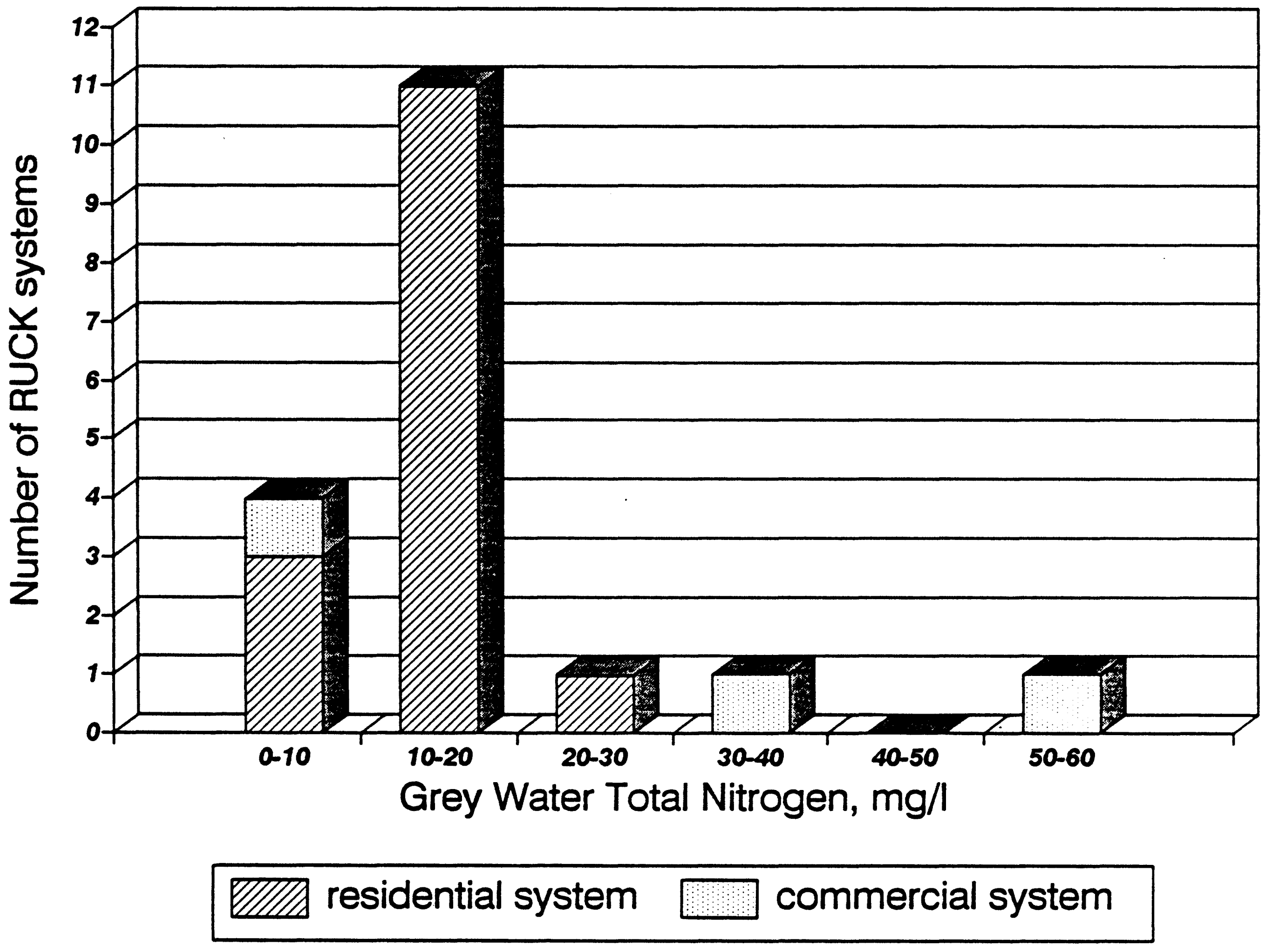
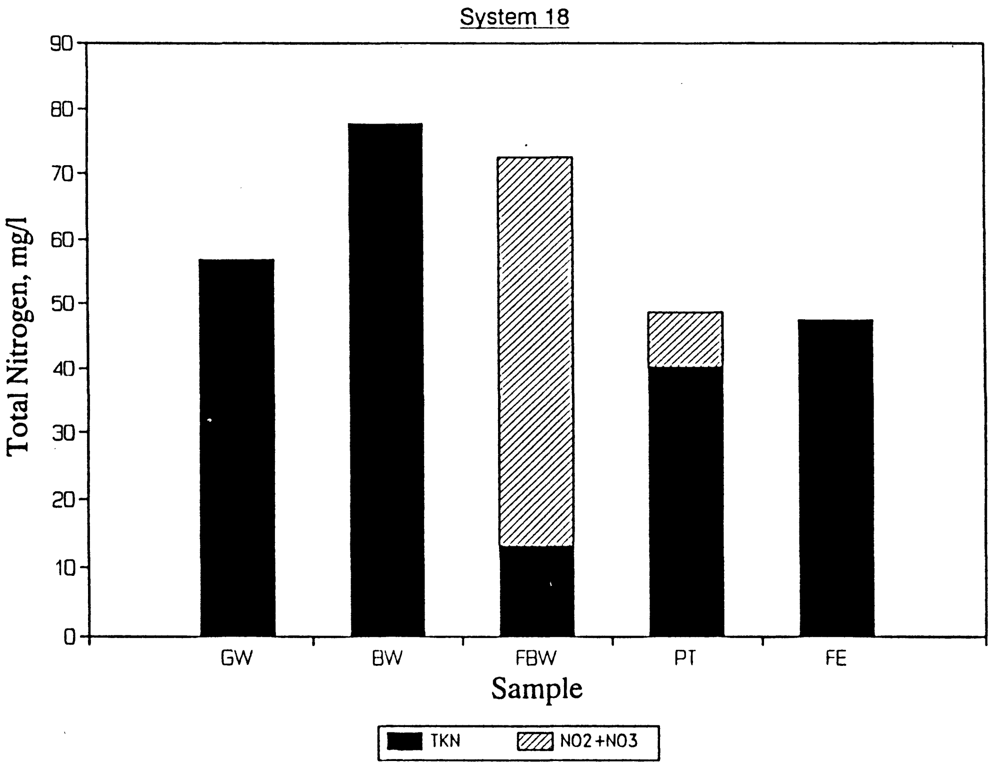


Figure 11. The distribution of average greywater total nitrogen concentrations for the monitored Pinelands RUCK systems.



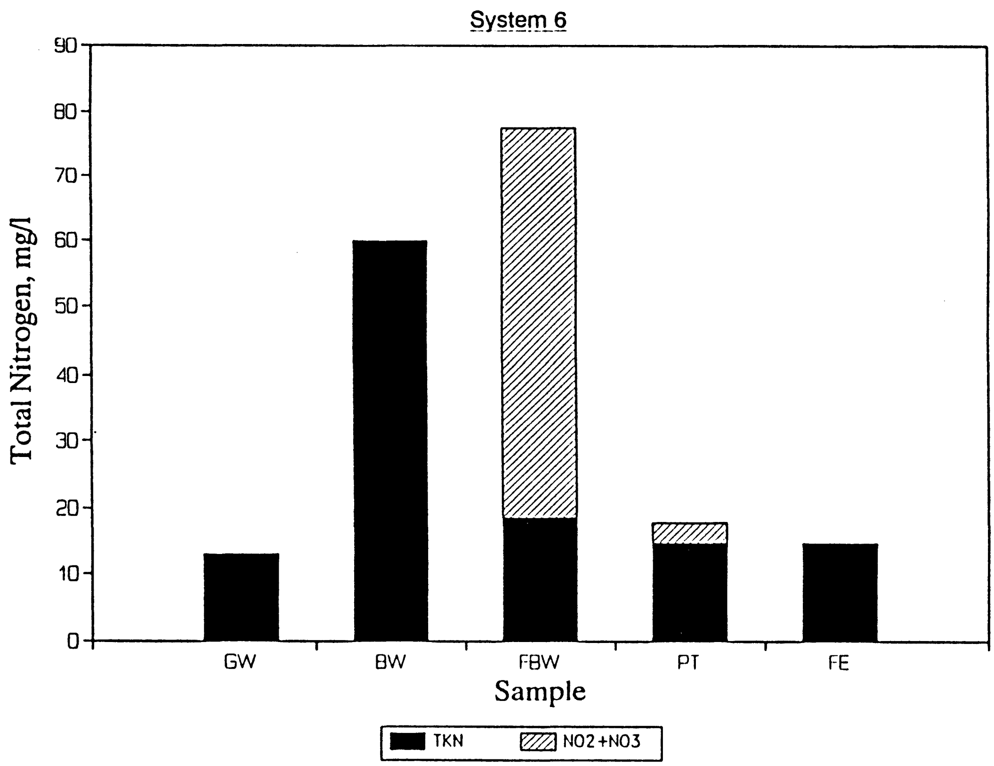


Figure 12. A comparison of average nitrogen levels at each sampling point for a RUCK system with a high greywater total nitrogen concentration (system 18) and a RUCK system with a low greywater total nitrogen concentration (system 6). The sampling points are the greywater tank (GW), the blackwater tank (BW), the filtered blackwater port (FBW), the pump tank (PT), and the rock tank also referred to as final effluent (FE). The total nitrogen concentration is divided into total Kjeldahl nitrogen (TKN) and NO_2+NO_3.

IIIE. RUCK System Problems

Several problems, some of which affected system function more than others, were encountered during the monitoring program. The problems include: 1. design and installation problems such as leaking tanks, inadequate reinforcement of tank lids, premature pump failure, pipe hook-up errors, sand filter construction errors, and pump installation errors; 2. maintenance and tampering problems such as failure to keep the pump operational and alterations to the system by the homeowner; 3. system application and operation problems such as garbage disposal attachment, addition of ammonia-containing substances to the greywater, and problems related to non-residential applications; 4. aesthetic and owner satisfaction problems such as odor, unsightly installations, and high installation cost; and 5. problems which also occur with standard septic systems such as drainfield failure and the presence of system odor. The following sections describe the nature and extent of the problems encountered. A summary of problems discovered through survey questionnaires and RUCK system inspections is given in Appendices 2 and 3.

IIIE1. High FETN at Pinelands Non-residential RUCK Systems

The three Pinelands non-residential systems were found to have higher than normal final (rock tank) effluent total nitrogen (FETN) concentrations due to the denitrification component not functioning adequately or to a high nitrogen concentration in the carbon source. System 9 had a high FETN concentration because of a low denitrification rate possibly caused by low total organic carbon in the greywater. Systems 17 and 18 had a high FETN concentration because of a high TKN concentration in the greywater which, at least for system 18, was caused by a toilet that was hooked up to the greywater tank to provide a carbon source for denitrification.

The primary problem with the Pinelands non-residential RUCK systems appeared to be the lack of carbon-containing washwater. At system 18, the greywater carbon-supply problem was solved by connecting a toilet to the greywater pipes. However, because the additional TKN introduced by the blackwater to the greywater was not treated by the RUCK system, the solution defeated the purpose of reducing the level of nitrogen in the final effluent.

IIIE2. Pump Failure

Depending on site conditions, RUCK systems can either be installed as passive, gravity-feed systems or installed with a pump between the sand filter and the rock tank . Most of the RUCK systems installed in the New Jersey Pinelands require a pump because of the flat terrain.

Premature pump malfunction appeared to be a major problem affecting Pinelands RUCK systems. Of the approximately eighty-eight RUCK systems currently in use in the Pinelands, at least twenty-four of the systems (27%) have had their pump malfunction at least once in the three to five years they have been in use. Of the eighteen monitored RUCK systems (the systems which have been in use the longest), twelve systems (67%) have experienced pump problems (systems 1, 2, 3, 4, 6, 10, 11, 13, 15, 16, 17 and 18). With one exception, pumps were repaired or replaced within a few weeks after failure.

IIIE3. Clogged Filter Fabric at the Sand Filter Discharge Line

An installation problem was realized at the beginning of the monitoring program. Filter fabric that had been placed over the sand filter discharge line was causing the system 1 sand filter to clog and the rock tank nitrogen concentration to increase (Appendix 5, system 1 FETN graph). Because of this, the filter fabric on the discharge line was removed from system 1 and from the other systems installed at the time. Since the removal of this filter fabric there have been no other cases of sand filter clogging. Even though sand filter clogging has not been of major concern for Pinelands RUCK systems, nitrification efficiency and clogging potential of RUCK system sand filters must be assessed as they age.

IIIE4. Leaking Tanks

A few probable cases of tank leakage were discovered at the beginning of the monitoring program. The tanks were patched and all new systems were installed with waterproof-coated tanks. None of the systems that have been sampled or inspected since have shown signs of tank leakage.

IIIE5. Installation Errors

Two RUCK systems were found to have reversed greywater and blackwater pipes. The switched pipes have been corrected at one of these systems (system 14). Appendix 5, graph 14 shows the improved nitrogen-removal performance at system 14 following the correction of the switched pipes.

Additionally, one RUCK system was found to lack a greywater tank outlet pipe (the pipe had been crushed either during or after installation) and one system was found to have the washing machine connected to the blackwater pipe instead of the greywater pipe.

IIIE6. Alterations Occurring After Installation

RUCK system alterations generally involve the shortening or moving of the sand filter vent pipes. Shortening the vent pipes does not appear to substantially lower sand filter nitrification.

Moving the vent pipes by extending them underground may possibly lower the sand filter nitrification, especially if the vents are moved a great distance, moved to a wind-protected location, or are not connected properly after being moved. Five of the monitored or inspected RUCK systems were found to have their vent pipes moved from the position indicated on the RUCK design. At least two of these systems had inefficient sand filter nitrification.

IIIE7. Inefficient Sand Filter Nitrification

Inefficient sand filter nitrification could be the result of low sand filter temperature, low sand filter pH, disposal of household chemicals, sand filter clogging, sand filter flooding, or insufficient air circulation. Improperly installed or altered sand filter vent pipes could lower the nitrification rate by reducing sand filter air circulation, and improper installation of internal sand filter components could lower the nitrification rate by reducing sand filter drainage and/or air circulation.

The RUCK monitoring program data suggest that when the water level in the sand filter vent pipes reached approximately five inches above the surface of the sand at the bottom of the vent pipes, the nitrification rate was adversely affected (systems with between one and three inches of standing water in their vent pipes were sometimes found to have a nitrification rate equal to or greater than systems with no standing water in their vent pipes). A sand filter water level of five inches or greater could be the result of clogging, improper drainage, or a malfunctioning pump.

Eight of the eighteen monitored RUCK systems (44%) had an average sand filter nitrification rate of less than 60%. Three of these systems had an average nitrification rate of less than 50%. Twenty of the fifty-eight RUCK systems (34%) that were inspected appeared to have a poor nitrification rate (Appendix 3). Five of these systems had a high water level in the sand filter because of a malfunctioning pump.

IIIE8. Garbage Disposal Use

Garbage disposal use has been shown to alter the performance of septic systems (Bendixen et al., 1961; U.S. EPA, 1980). Only one Pinelands RUCK system is known to have been hooked to a garbage disposal unit. The garbage disposal did not appear to seriously hamper the functioning of this system.

IIIE9. Drainfield Problems

Two of the eighteen monitored RUCK systems had drainfield problems which may or may not have been related to the RUCK system. Prior to July 1989, the drainfield at system 17 was not draining properly. This drainfield began functioning normally after the pipe between the pump tank and the rock tank was raised. In August 1989, the mounded drainfield at system 14 was leaking from its far end. It is not known if this problem was corrected.

IIIE10. Inadequately Reinforced Pump Tank Lids

The integrity of pump tank lids, which must be removed during pump maintenance, is important for safety reasons. In August 1987, a RUCK system pump tank lid broke due to inadequate reinforcement. The RUCK system installer immediately replaced the lid and the lid manufacturer began to put extra reinforcement in all new lids. In June 1989, the manufacturer replaced three cracked pump tank lids which were installed prior to the date that the lids were extra-reinforced.

Of the fifty-eight RUCK systems that were inspected, seven systems had cracks in the surface of their pump tank lids. These lids had supposedly been extra-reinforced.

IIIE11. Odor

Five owners of monitored or inspected Pinelands RUCK systems reported unpleasant odors from their systems. One RUCK system owner complained of odor caused by a sand filter vent pipe that was located too close to his deck. He contacted the RUCK system inventor who suggested that the vent pipes be extended to the roof of the house. It was determined that extension of the vent pipes to the roof did not require Commission approval because it could be considered a repair of an existing utility. As of September 1989, the owner had not changed the location of the vent pipe.

IIIE12. System Appearance

At least ten owners of monitored or inspected Pinelands RUCK systems complained about the appearance of the system in their yards. The appearance of the vent pipe(s) and the appearance of the concrete pump tank lid were the two most common appearance-related complaints.

IIIE13. System Cost

Eleven RUCK system owners complained via the survey questionnaire about the cost of installing the RUCK system (Appendix 2). Other RUCK owners (especially those who experienced installation or maintenance problems) complained directly to Pinelands Commission staff about the RUCK system's cost.

IIIG. Comparison with RUCK systems in other states

The residential Rhode Island RUCK systems studied by Gold et al. (1990) were comparable in function to the New Jersey residential systems except that they had a higher estimated blackwater total nitrogen concentration entering the sand filter (Rhode Island BWTN = 148-251 mg/l, Pinelands BWTN = 31-104 mg/l) and one of the two Rhode Island systems had a higher greywater total nitrogen concentration, a lower denitrification rate, and a higher final effluent total nitrogen concentration than the New Jersey systems (Gold et al., 1990).

Other RUCK system studies include a RUCK test installation in East Falmouth, Massachusetts (Dudley et al., 1989) and a non-passive RUCK system installed at a California Department of Transportation inspection station (Danielson, 1989). The design of the California Department of Transportation system differs from that of the systems studied in the New Jersey Pinelands. The California system is a modified RUCK system which is highly controlled, intensively maintained, and costly. This system experiences a 95% nitrogen-removal rate due to a two stage nitrification process which has a mechanical aeration device, the mechanical addition of methanol as a carbon source, and monthly monitoring.

The Massachusetts RUCK test installation experienced problems including installation errors (holes in the bottom of the septic tanks were left open), a poor denitrification rate due to an inadequate carbon supply, fluctuating nitrification rates, and rock tank clogging (a problem not experienced by Pinelands RUCK systems)(Dudley et al., 1989).

IV. Summary and Conclusions

The average final effluent total nitrogen concentration for the fifteen Pinelands residential RUCK systems studied was 19.9 mg/l (standard error = 2.1) compared to the approximately 40 mg/l average total nitrogen concentration reported for the effluent of conventional septic systems (Hickey and Duncan, 1966; Trela and Douglas, 1979; Brown, 1980; Canter and Knox, 1985). Based on an estimated average total nitrogen input of 43.5 mg/l (standard error = 1.5), calculated using U.S. EPA (1980) greywater:blackwater flow ratios and measured greywater and blackwater nitrogen concentrations, the fifteen Pinelands residential RUCK systems had an estimated total nitrogen removal of 54% (standard error = 4.7%). Although this removal rate is relatively high, it is less than the 71-81% removal indicated by preliminary testing (Laak et al., 1981; Laak, 1982) and the 65% removal initially assumed by the Pinelands Commission.

Using the Brown (1980) dilution model and a final effluent total nitrogen concentration of 19.9 mg/l, 1.4 to 1.5 acres (on B and A soils, respectively) is the minimum parcel size required for residential RUCK systems to meet the Pinelands Comprehensive Management Plan 2 mg/l nitrate-nitrogen groundwater standard.

Compared to the Pinelands residential RUCK systems, the three monitored Pinelands non-residential RUCK systems had greater concentrations of nitrogen in the final effluent. The average final effluent total nitrogen concentration for the non-residential systems ranged from 27.9 mg/l to 52.6 mg/l. The non-residential systems had high final effluent total nitrogen concentrations due to a high nitrogen concentration in the carbon source or inadequate denitrification. Low denitrification may have been due to low greywater carbon. The potential lack of an adequate greywater carbon supply and the diversity of non-residential wastewater characteristics and loadings does not permit an average rock tank effluent nitrogen concentration or an average nitrogen removal rate to be determined for non-residential RUCK systems in general.

Factors that lead to decreased nitrogen removal rates include incomplete sand filter nitrification, incomplete denitrification, and elevated greywater total Kjeldahl nitrogen concentrations. The main factor limiting nitrogen removal for the Pinelands residential RUCK systems was incomplete sand filter nitrification. Incomplete denitrification or nitrogen in the greywater seriously limited nitrogen removal for the Pinelands non-residential RUCK systems.

The average nitrification rate for the residential Pinelands systems was 57% (standard error = 5.2%). None of the Pinelands systems studied provided complete sand filter nitrification; 80%

nitrification was the greatest observed for a monitored Pinelands RUCK system. Factors that may limit sand filter nitrification include low sand filter temperature, low sand filter pH (and alkalinity), and low sand filter oxygen concentration. Two of the Pinelands residential systems had very low nitrification rates due to malfunctioning sand filters. Sand filter malfunction may be caused by improper vent pipe alterations, errors in vent pipe design or installation, or sand filter saturation (sand filter saturation may be due to pump malfunction or errors in RUCK system design or installation resulting in improper loading rates or poor sand filter drainage).

With the exception of one non-residential system, all Pinelands RUCK systems had denitrification rates that were consistently greater than 90%. Eleven of the systems had 100% denitrification on all dates sampled. The low denitrification rates observed for the non-residential system probably resulted from the lack of an adequate greywater carbon supply.

One residential system and two non-residential systems had elevated greywater total Kjeldahl nitrogen (TKN) concentrations. The elevated greywater TKN concentrations may have been caused by a portion of the blackwater being diverted to the greywater tank or the disposal of ammonia-based cleaners or other nitrogen-containing substances through the greywater.

Several problems, some of which affected system function more than others, were encountered during the Pinelands RUCK monitoring program. The problems include: 1. design and installation problems such as leaking tanks, inadequate reinforcement of tank lids, premature pump failure, pipe hook-up errors, sand filter construction errors, and pump installation errors; 2. maintenance and tampering problems such as failure to keep the pump operational and alterations to the system by the homeowner; 3. system application and operation problems such as use of a garbage disposal unit, addition of ammonia-containing substances to the greywater, and problems related to non-residential applications; 4. aesthetic and owner satisfaction problems such as odor, unsightly installations, and high installation cost; and 5. problems which also occur with standard septic systems such as drainfield failure and the presence of system odor.

Premature pump malfunction was the major problem affecting numerous Pinelands RUCK systems. Twelve of the eighteen monitored systems experienced pump problems at least once in the three to five years of use. Most of the pumps were repaired or replaced soon after failure; however, the pump at one system remained non-functional for over two years. Other significant problems include the mix-up of the blackwater and greywater pipes during installation, the alteration of the sand filter vent pipes after installation, and the aesthetic and installation cost concerns of the homeowners.

V. Recommendations

1. A final effluent nitrogen concentration of 19.9 mg/l rather than an estimated nitrogen removal rate should be used when determining minimum residential lot sizes for RUCK system use in the Pinelands. This assumption generally results in a minimum lot size of 1.4 to 1.5 acres to meet the Pineland's 2 mg/l nitrate-nitrogen groundwater standard.

2. Non-residential RUCK systems tend to lack a greywater carbon source and, thus, may not be able to passively produce low nitrogen concentration effluent through denitrification. The addition of a carbon source to the greywater of non-residential systems may be an alternative only if the carbon source has a low nitrogen concentration and if the carbon source addition mechanism is reliable. The results of this investigation do not, however, provide the basis for an accurate determination of the nitrogen removal ability of non-residential RUCK systems.

3. Because various installation and maintenance problems, which proved to be detrimental to system performance, were found at certain Pinelands systems, proper system performance should be ensured by inspection of the systems during construction, prior to use, and at defined intervals while the system is in use. To accomplish this, a consistent, regional RUCK management program should be developed and implemented.

4. Additional study is warranted to determine the long term nitrification efficiency and clogging potential of the sand filter, to more clearly define factors affecting RUCK system nitrification and denitrification rates, to determine ways of decreasing the pump failure rate when pumps are required, to determine ways of reducing system cost without sacrificing function, to determine whether changes in sand filter or vent pipe design would increase the nitrification rate while maintaining the system's passive feature, and to determine the nitrogen removal which would be expected for particular non-residential RUCK system applications.

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Appendix 1. The nitrogen cycle (Pinelands Comprehensive Management Plan, 1980; Dudley et al., 1989)

DEFINITIONS: Total nitrogen (TN) = total Kjeldahl nitrogen (TKN) + Nitrate (NO_3) + Nitrite (NO_2)

Total Kjeldahl nitrogen (TKN) = ammonium (NH_4^+) + organic nitrogen

1. AMMONIFICATION: The transformation of organic nitrogen to ammonia or ammonium. Ammonification can occur in the septic tank.

$$\text{Organic N} \xrightarrow{\text{microorganisms}} NH_3 \text{ and/or } NH_4$$

2. NITRIFICATION: The oxidation of ammonia or ammonium to nitrate. Nitrification is a two step aerobic process with nitrite as the intermediate.

$$NH_4^+ + 3/2O_2 \xrightarrow{\text{nitrosococcus or nitrosomonas}} NO_2^- + 2H^+ + H_2O$$

$$NO_2^- + 1/2O_2 \xrightarrow{\text{nitrobacter}} NO_3^-$$

3. DENITRIFICATION: The reduction of nitrate to nitrogen gas, an inert gas that is abundant in the atmosphere. Denitrification requires the presence of a carbon source along with anaerobic conditions.

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

Appendix 2. Questionnaire summary

Appendix 2a. Owner questionnaires were sent to the owners of the monitored RUCK systems every three months regarding factors which could affect the performance or wastewater quality of their RUCK system. The following table summarizes these questionnaires. Please note that the number of times (eg 4x) for each item are for the entire study period. Also please note that this table is only as accurate as the answers obtained by the homeowners. Because survey accuracy depended on the homeowners memory and commitment to providing the correct responses, no comparisons were made between system function and survey results.

System	# in household	main detergent brand	bleach used	cleaners, etc. disposed of	garbage disposal	water-saving devices	dripping fixtures	water cond-itioner	where the conditioner flushes	comments
1	2	All	Yes	none	No	none	none	Yes	not into septic tank	the system smells
2	4	Era/Tide	Yes	none	No	showers	none	Yes	do not know	none
3	2	Wisk/All/Tide	Yes	paint 1x pet wastes routinely	No	shower	none	No	N/A	pump failed alarm too loud erosion near system
4	4	Tide	Yes	ammonia floor cleaner 25x paint 1x	No	not sure	kitchen sink 2x	Yes	greywater tank	none
5	5	Tide	Yes	ammonia floor cleaner 57x	No	toilets	kitchen sink 11x	Yes	greywater tank	none
6	2	All	Yes	ammonia product 4x	No	none	none	No	N/A	the system smells
7	3	Amway	No	ammonia 9x draino 2x	No	showers	none	No	N/A	none
8	4	Era	Yes	ammonia 11x, paint 2x	No	none	none	Yes	do not know	none
9	doctors office	N/A	N/A	none	No	none	none	Yes	do not know	none

Appendix 2a. continued.

System	# in household	main detergent brand	bleach used	cleaners, etc. disposed of	garbage disposal	water-saving devices	dripping fixtures	water cond-itioner	where the conditioner flushes	comments
10	4	Surf/Fab	Yes	Pinesol	No	none	kitchen sink 1x	Yes	drywell	pump failed
11	5	Wisk	Yes	paint 2x ammonia 4x	No	none	kitchen sink 1x	Yes	drywell	none
12	6	a variety	Yes	ammonia 1x per week paint and thinner 1x	No	none	none	Yes	not into septic tank	none
13	6	Arm & Hammer	No	ammonia 12x Pinesol	No	toilets	none	No	N/A	pump failed alarm went off toilets backed up
14	4	a variety	Yes	ammonia floor cleaner 39x	No	not sure	washing machine 1x	Yes	outside	drainfield leaks BW & GW pipes were switched
15	3	Ajax/Bold	Yes	ammonia 56x paint and thinner 2x wall paper paste 1x	Yes	shower	none	No	N/A	pump was not properly connected (this was fixed)
16	4	Tide	Yes	ammonia 71x	No	none	none	Yes	outside	the system smells pump ran continuously pump failed system clogged toilets backed up
17	shopping center	N/A	N/A	none	No	none	none	No	N/A	drainfield saturated pump replaced
18	service station	N/A	N/A	ammonia (daily)	No	none	none	Yes	drywell	pump failed

Appendix 2. continued.

Appendix 2b. Survey questionnaires were sent to as many Pinelands RUCK owners as possible at the completion of the monitoring program to determine the extent of homeowner satisfaction with the system. Of the 79 questionnaires sent, 56 were returned plus personal communication was received from eight owners (an 81% return rate). The results of the questionnaire survey are, 19 owners (30%) were satisfied with their systems and 45 owners (70%) had one or more RUCK system problems or complaints. Following is a table listing the problems or complaints referenced by the 45 owners.

Problem or Complaint	Number of Owners with the Problem or Complaint
- high installation cost, system overpriced	11
- pump failed, pump inadequate	10
- poor service by the installer	8
- system is unsightly	7
- the engineer has a monopoly	6
- was forced to use the system	4
- no information or instructions were provided	4
- the system smells	3
- the engineer or installer raised the quoted price	3
- poor backfilling or a delay in backfilling	3
- clogging at the inlet to the blackwater tank	2
- system installed too high in yard	2
- system installed too close to house	2

Following are individual problems or complaints which were indicated: was charged for repairs that should have been under warranty, vent pipes were not installed according to design, system was installed improperly, the alarm sounds for no apparent reason, sample ports have broken threads, water collects in the sample ports, soil is settling around the vent pipes, incorrect measurements were provided on the as-built plan, the electric to the pump was never connected, the system was not checked after installation, the tank covers are poorly designed.

Appendix 3. RUCK system inspection summary.

Between April and June of 1990, fifty-eight RUCK systems, which were not routinely monitored, were inspected. The inspection included a visual inspection of the system's layout and an inspection of the water level in each tank. It also included an interpretation of the color and appearance of a filtered blackwater sample in order to estimate whether the sand filter was functioning satisfactorily.

During the intensive study of the eighteen Pinelands RUCK systems, it was found that clear to very clear filtered blackwater usually indicated optimal nitrification rates and that cloudy and/or yellow-colored filtered blackwater usually indicated below optimal nitrification rates. Although definite conclusions regarding the nitrification rates for RUCK systems would have to be made by chemical analysis of the filtered blackwater over time, visual inspection of the filtered blackwater did provide a rough estimate of sand filter performance that was useful for general survey purposes. Following are the results of the visual analysis of the filtered blackwater:

Seven of the fifty-eight systems inspected had mechanical or installation problems. These consisted of five systems with malfunctioning pumps, one system with switched blackwater and greywater pipes, and one system that lacked an outlet pipe on the greywater tank. Filtered blackwater samples were not obtained from these seven systems. Filtered blackwater samples were collected from the remaining fifty-one systems. Judging by the appearance of the filtered blackwater, the sand filters were operating satisfactorily in thirty-six systems and less than satisfactorily in the remaining fifteen systems.

In summary, thirty-six of the fifty-eight systems inspected (62%) appeared to be functioning satisfactorily whereas twenty-two of the systems inspected (38%) appeared to be functioning unsatisfactorily due to mechanical problems, installation problems, or poor sand filter performance.

Appendix 4. Methods and assumptions for the estimation of blackwater flow ratios and greywater flow ratios (Nicholson, 1986).

A mass balance equation for chloride across the pump tank of the RUCK system:

$$F_gC_g + F_bC_b + (F_g + F_b)C_t$$

algebraically,

$$R \text{ (defined as } F_g/F_b) = (C_b - C_t)/(C_t - C_g)$$

where
F_g = greywater flow rate
F_b = blackwater flow rate
C_g = greywater chloride concentration
C_b = blackwater chloride concentration
C_t = pump tank chloride concentration

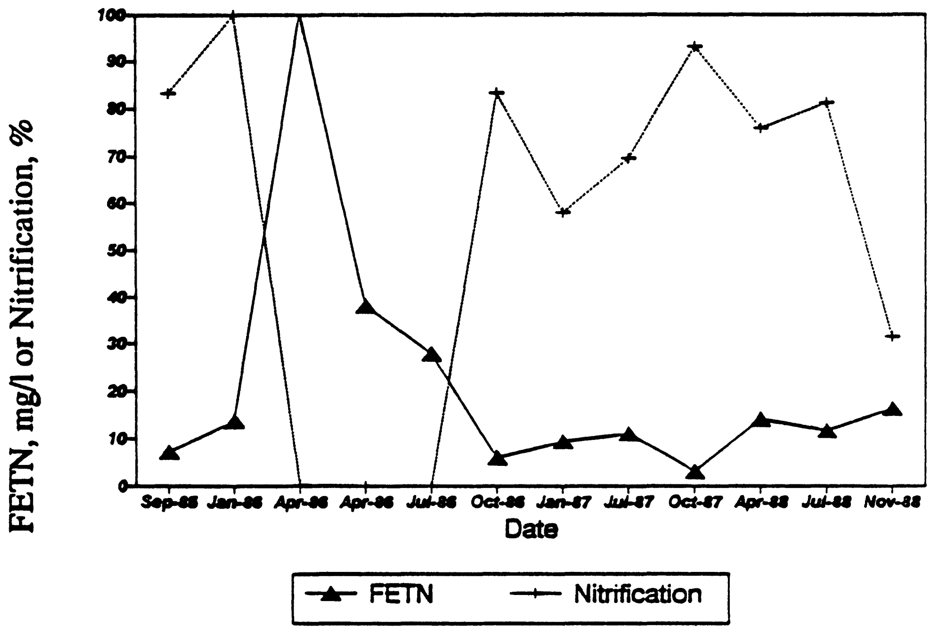
assumptions:

1. Chloride is a conservative ion.
2. The pumping chamber (and the sand filter) does not leak.
3. Nitrogen is not removed, only changes form, in the sand filter.
4. * The waste stream entering each septic tank has consistent chloride concentrations or the same waste stream is grabbed when samples are collected from either of the septic tanks and the pump tank.

* Assumption 4 does not hold true.

Appendix 5. Final effluent total nitrogen and sand filter nitrification by sample date for each of the monitored Pinelands RUCK systems. The number above each graph is the system number.

1



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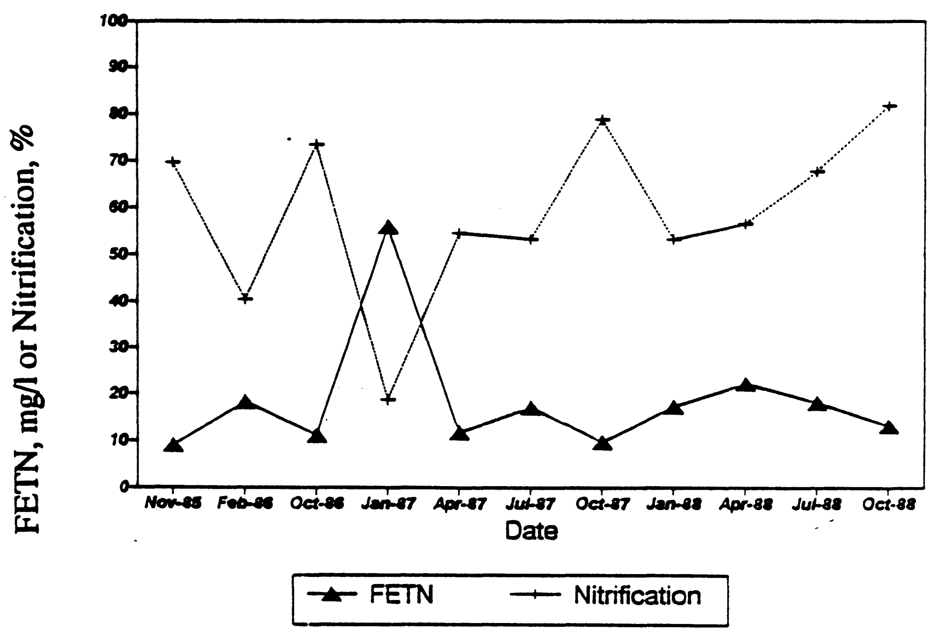
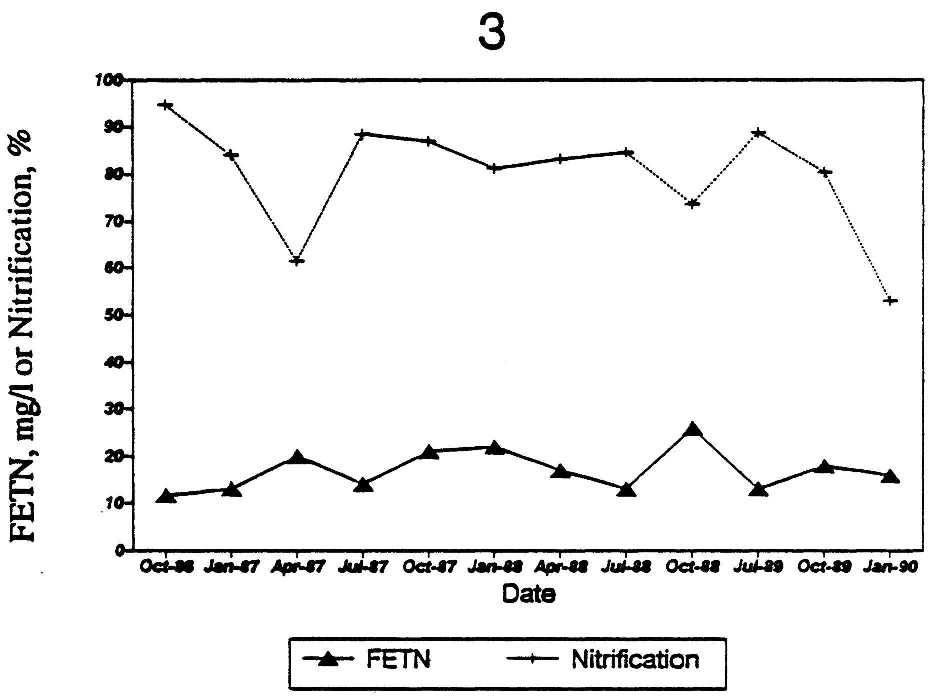
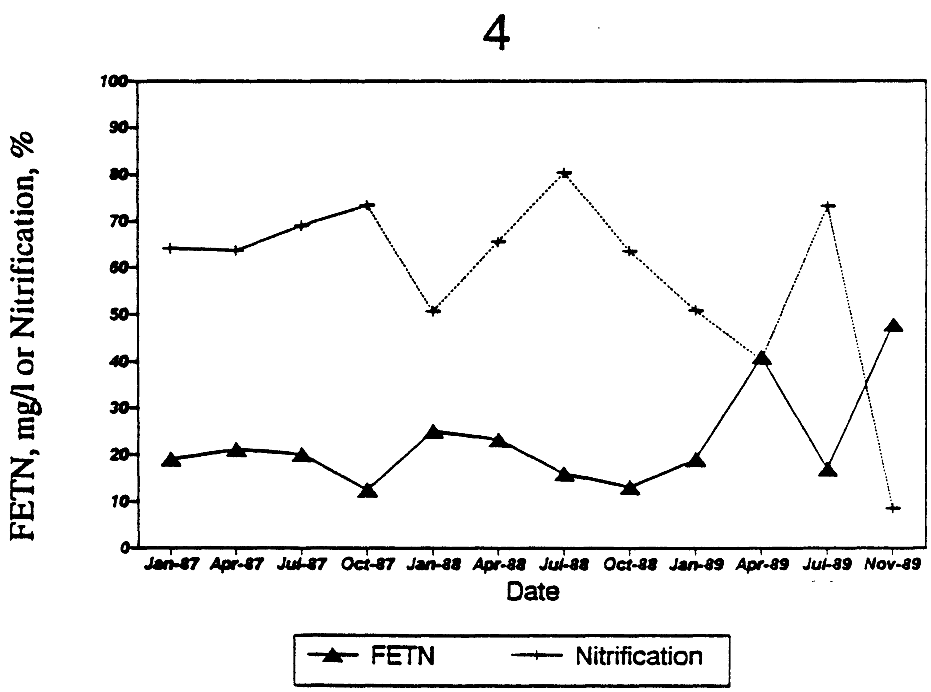


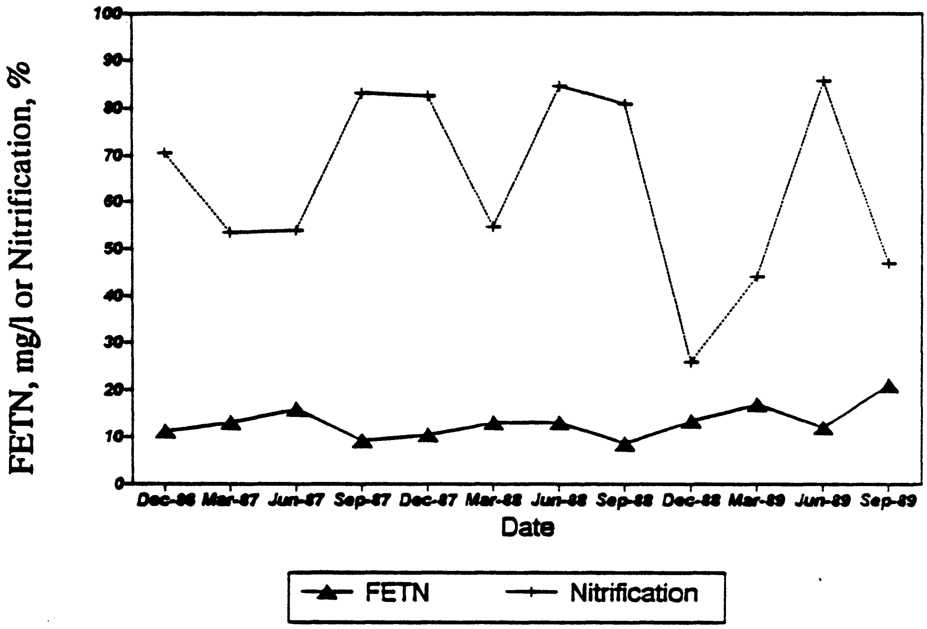
Appendix 5. continued.



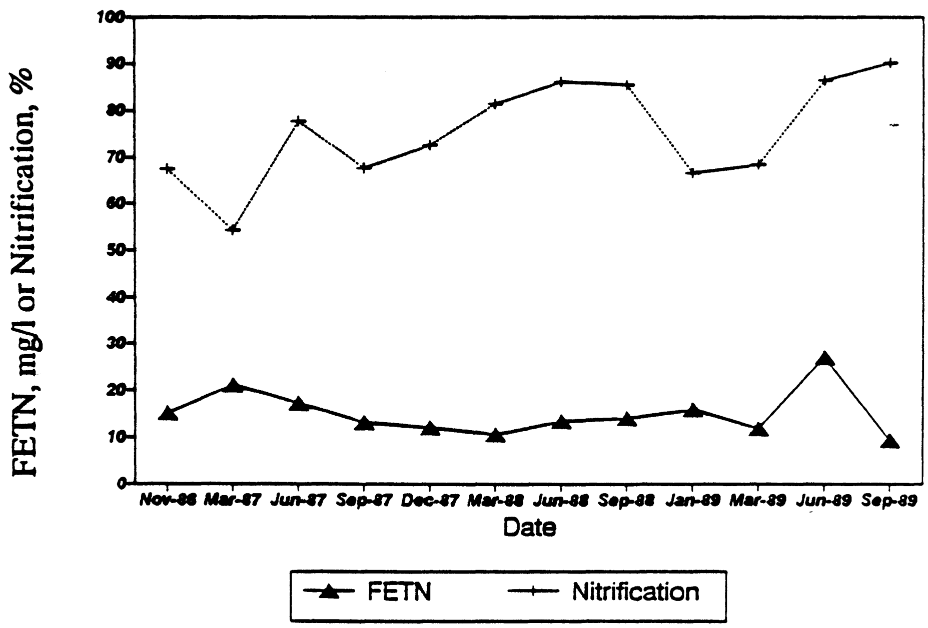


Appendix 5. continued.

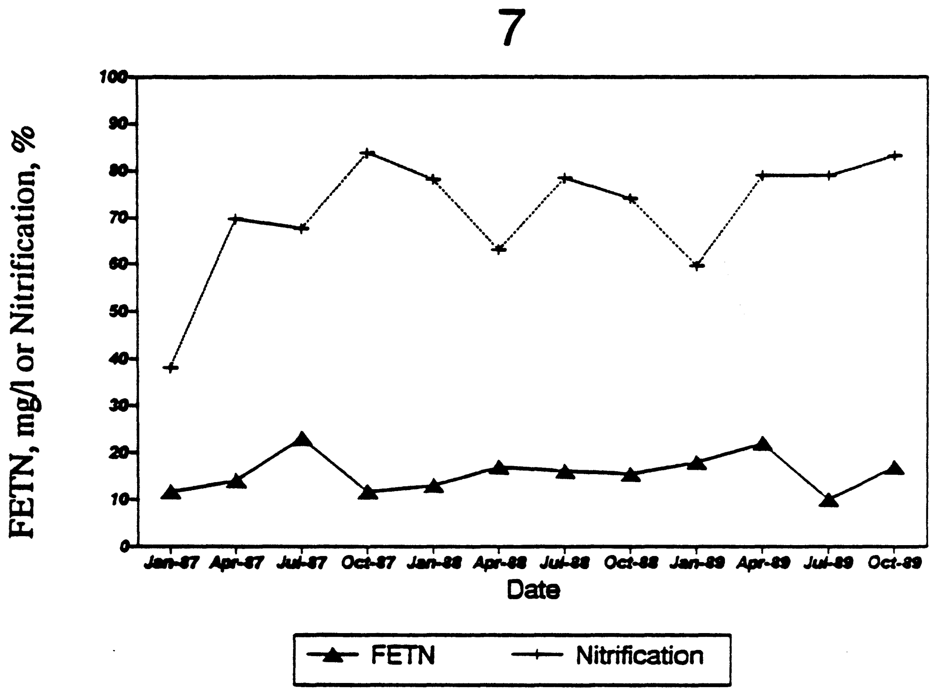
5

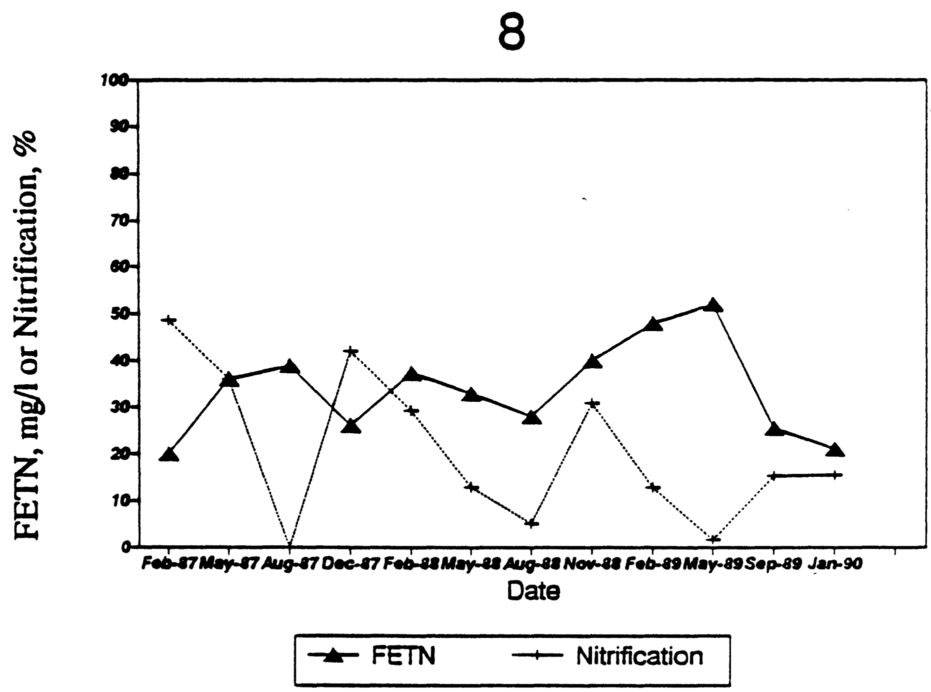


6



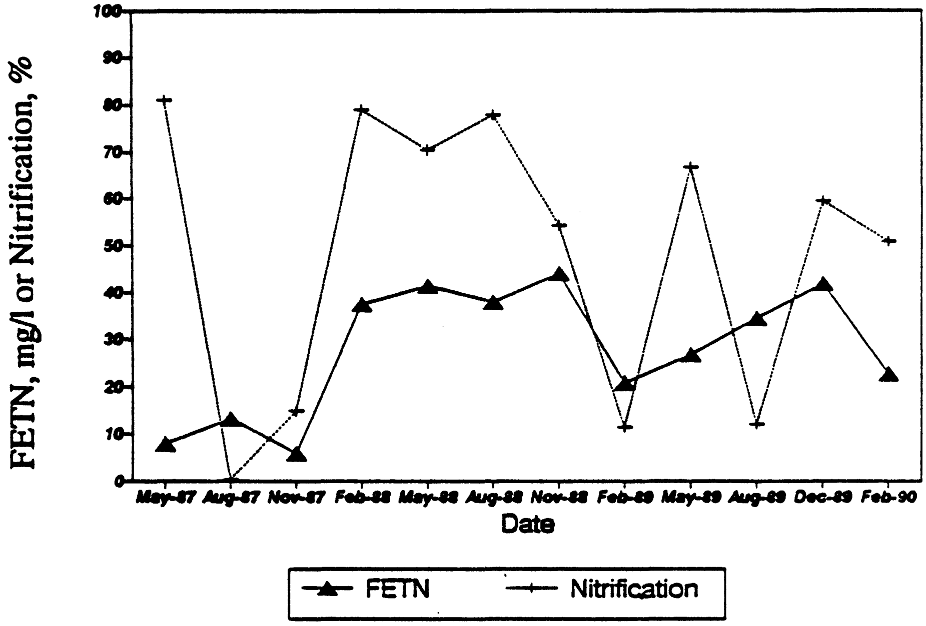
Appendix 5. continued.





Appendix 5. continued.

9



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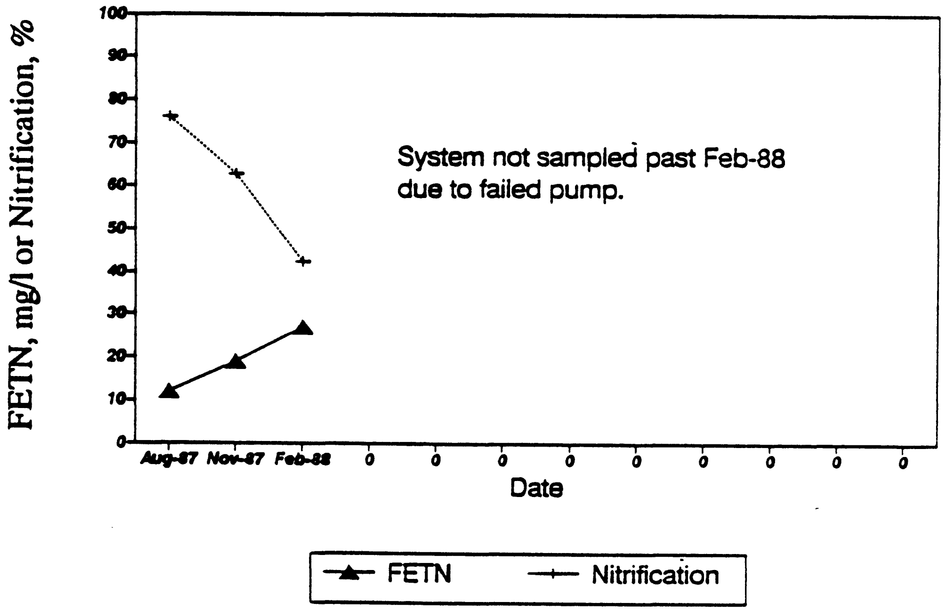

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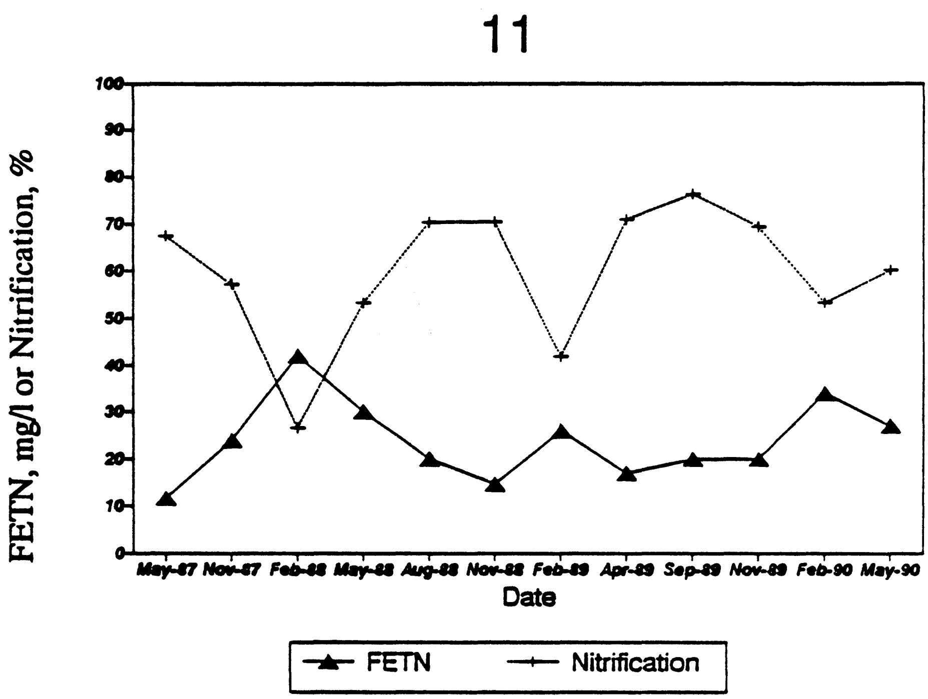

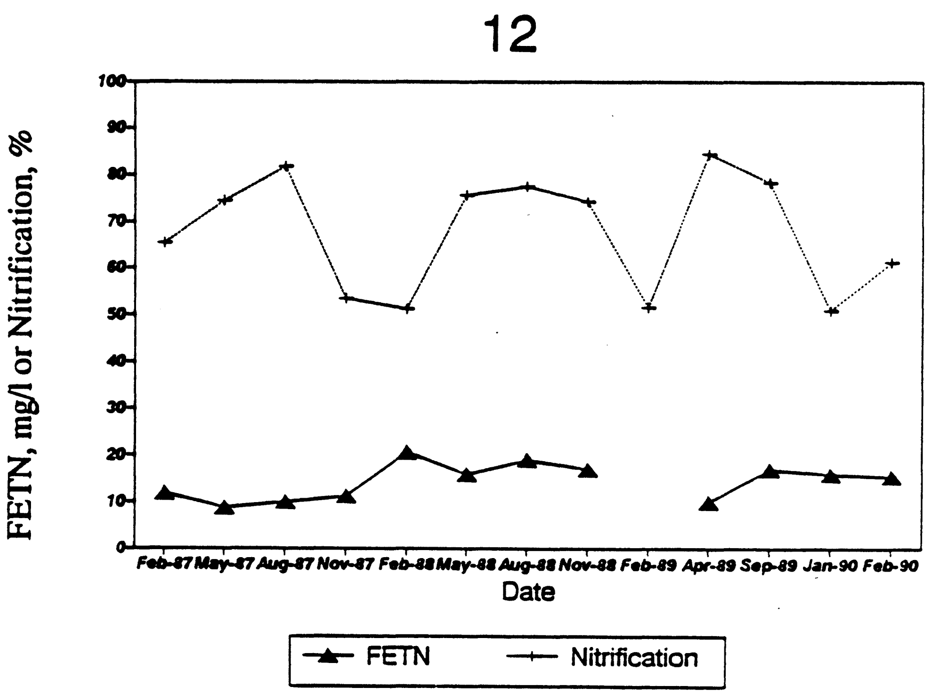

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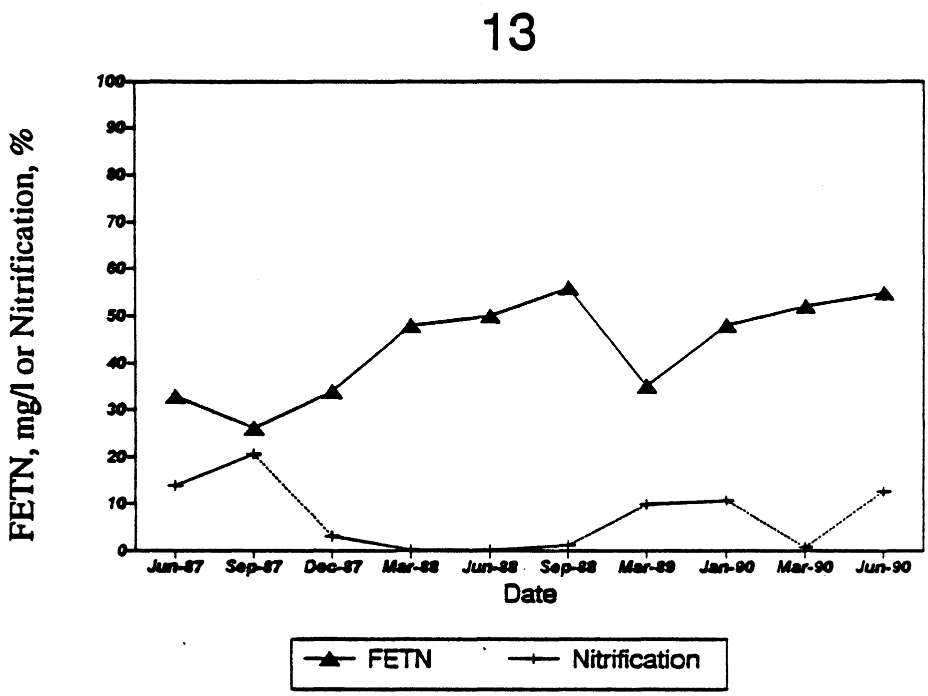

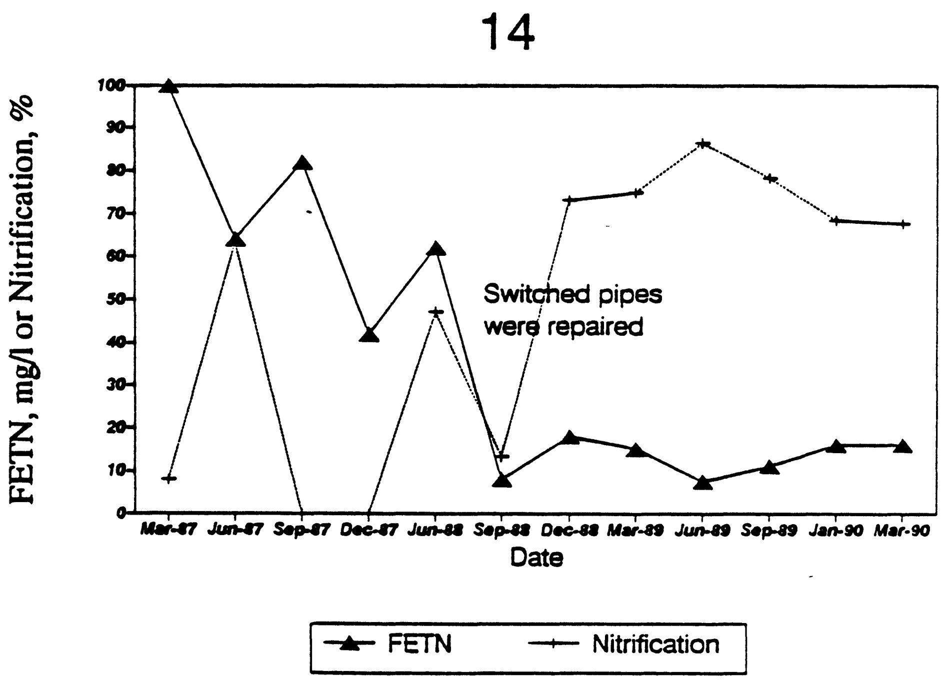

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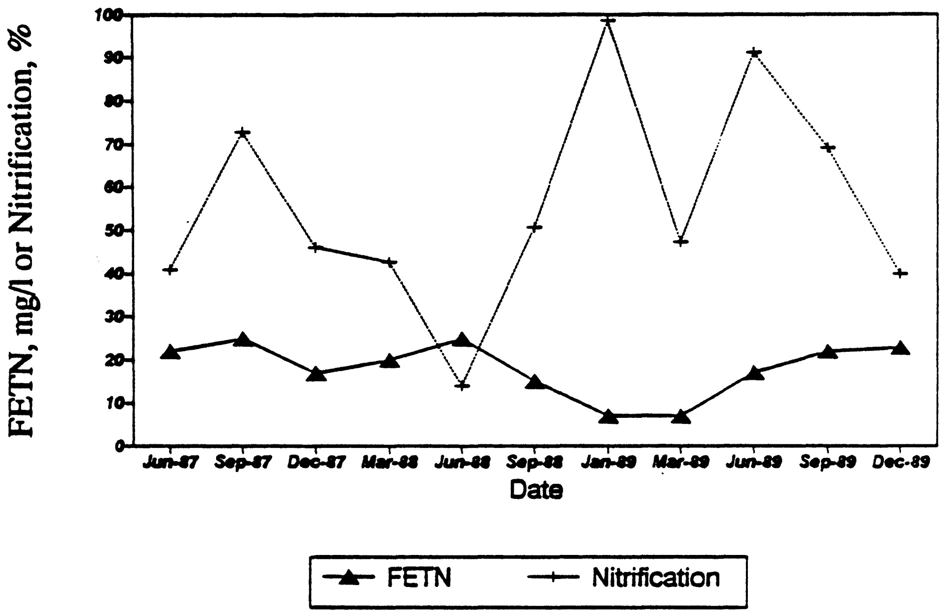
15



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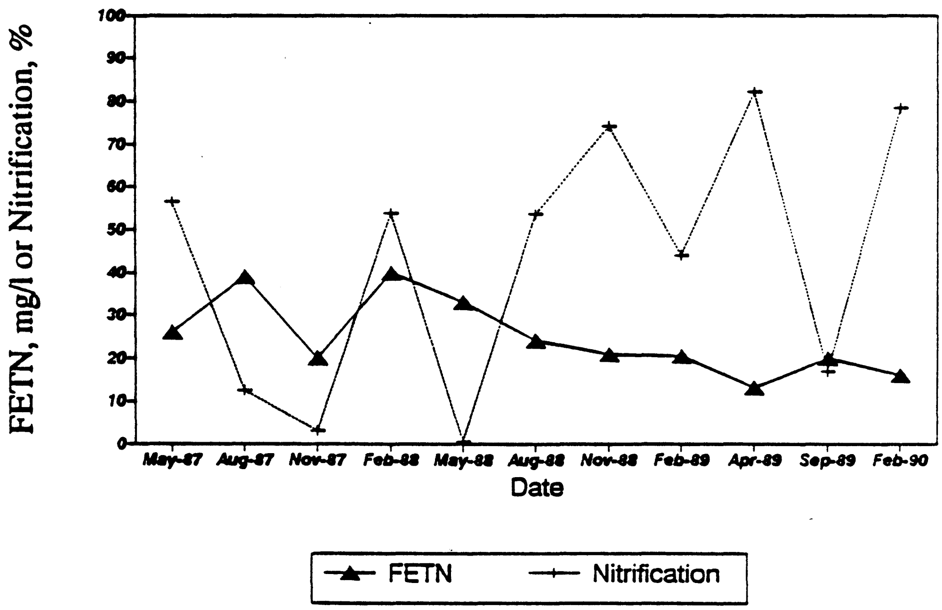
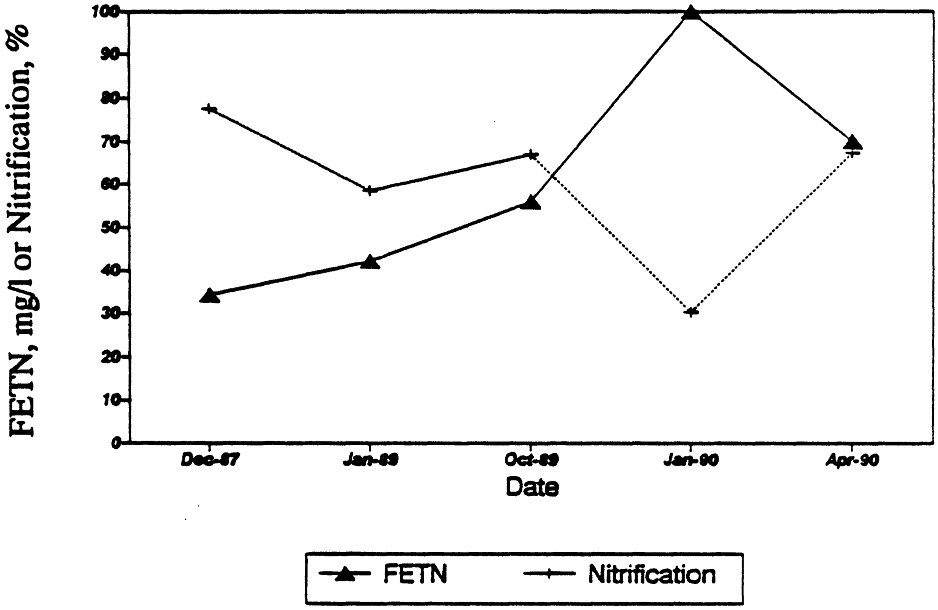


Appendix 5. continued.

17



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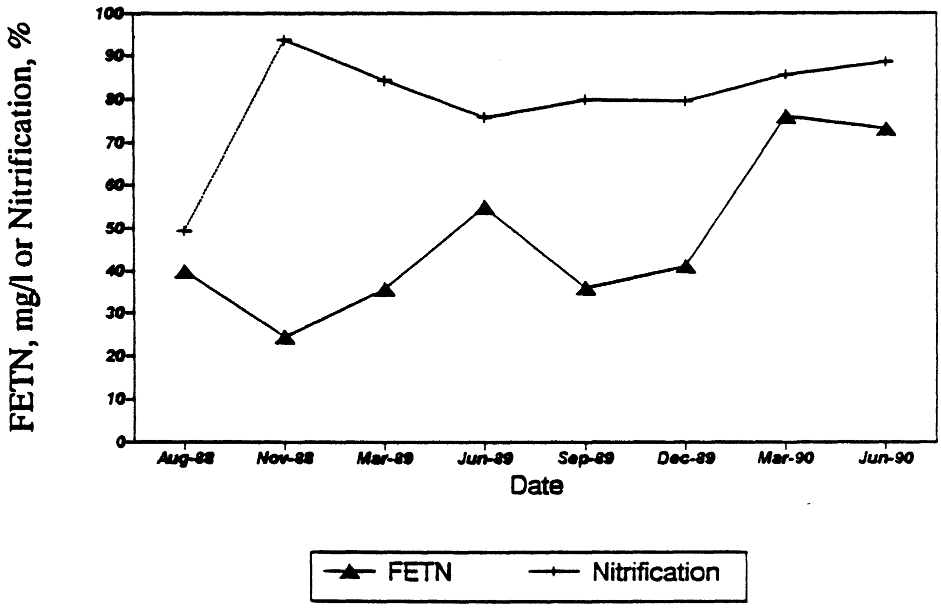
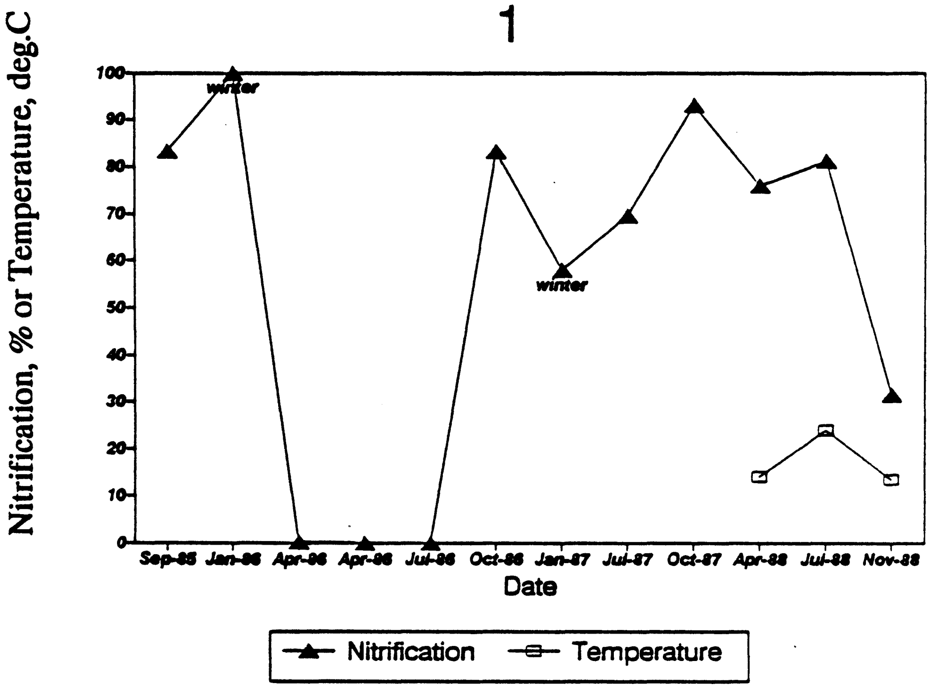
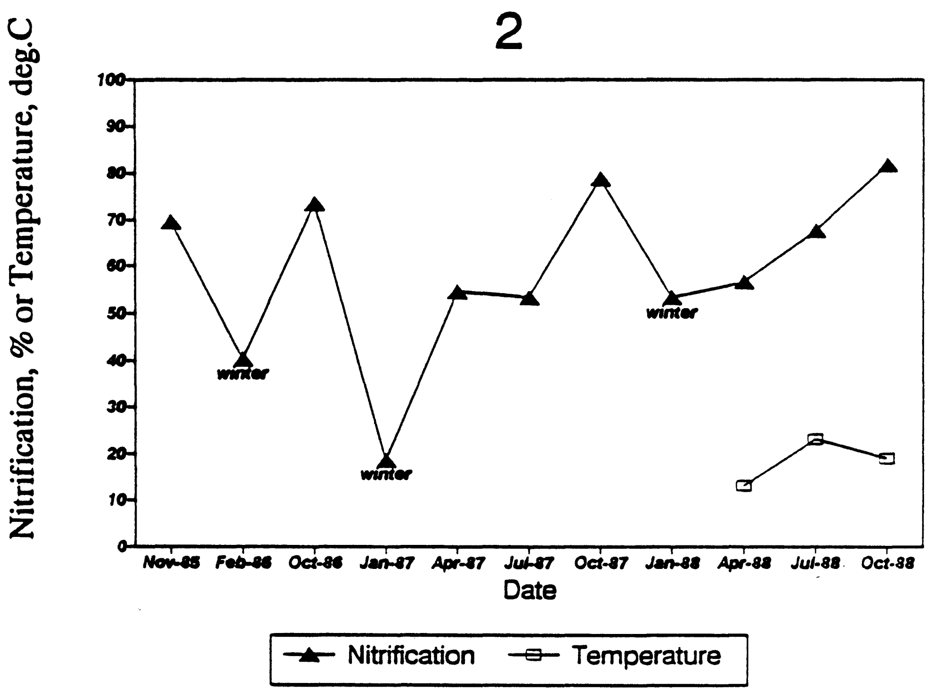


Appendix 6. Sand filter nitrification and sand filter temperature by sample date for each of the monitored Pinelands RUCK systems. The number above each graph is the system number (no temperature readings were taken for system 10).





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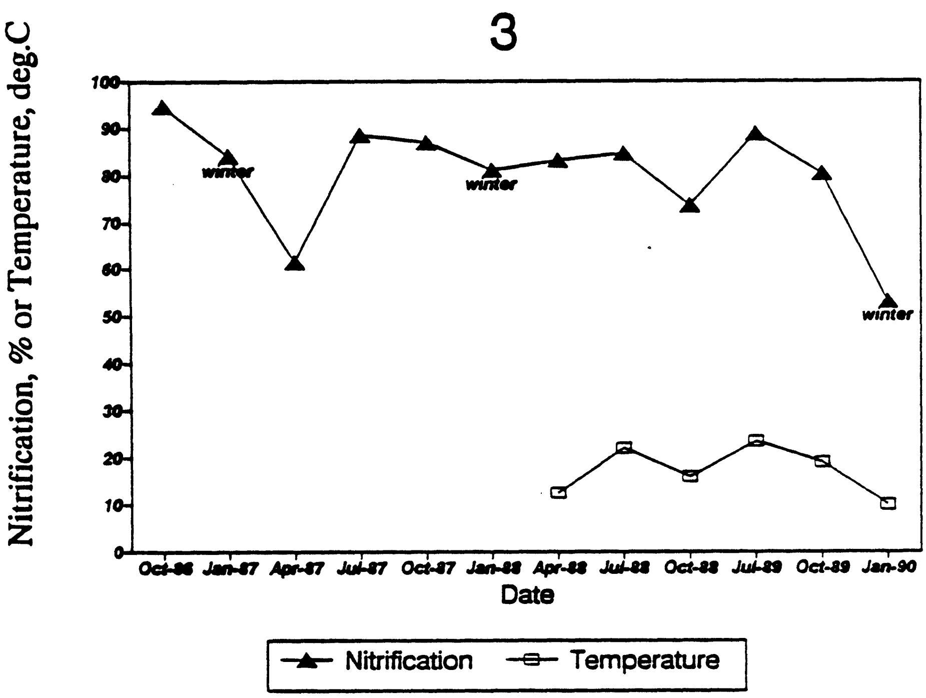
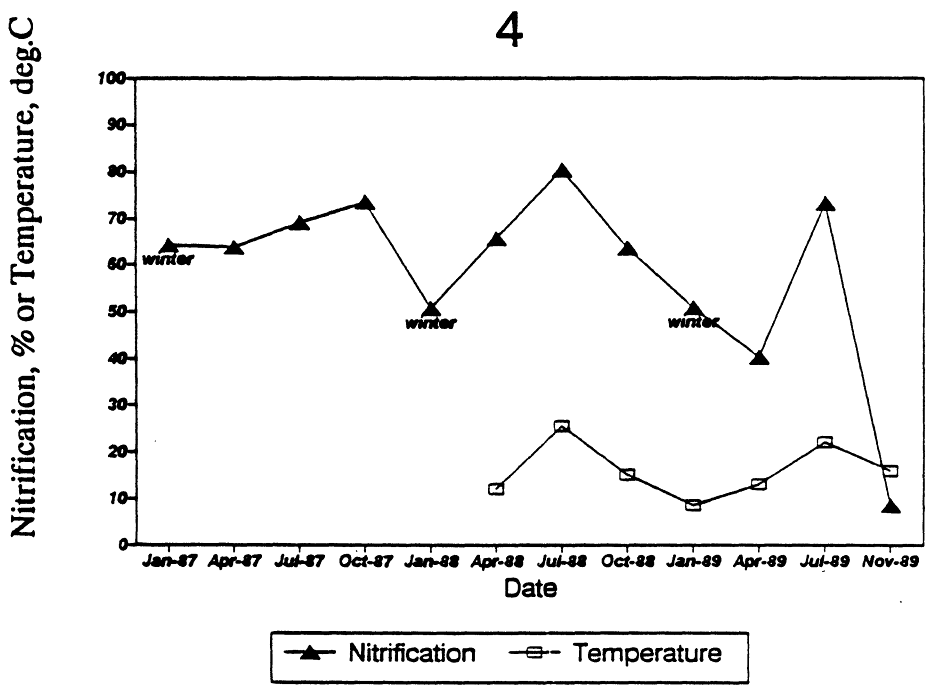
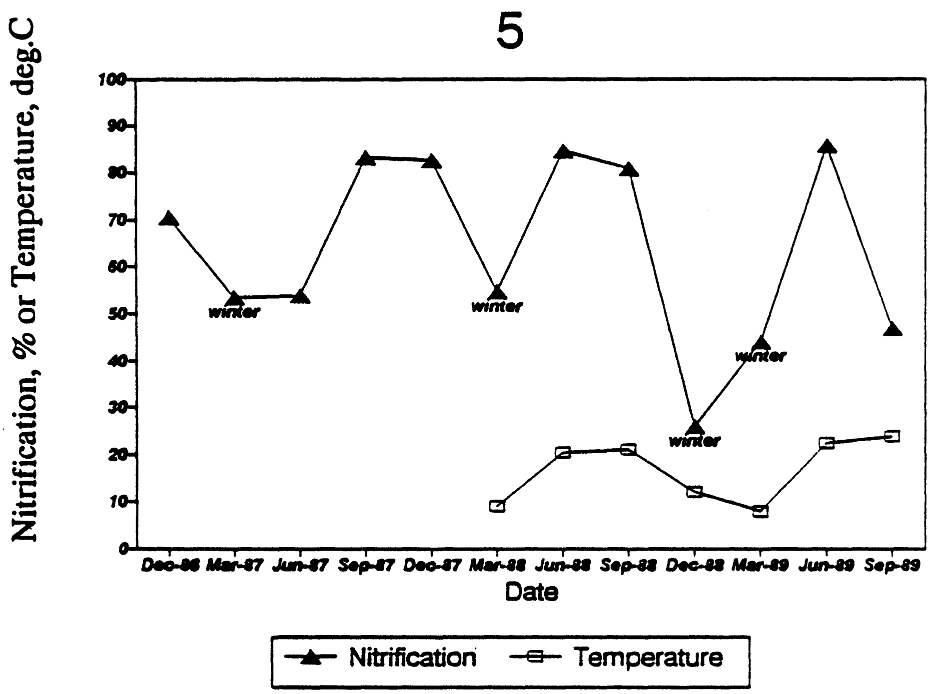
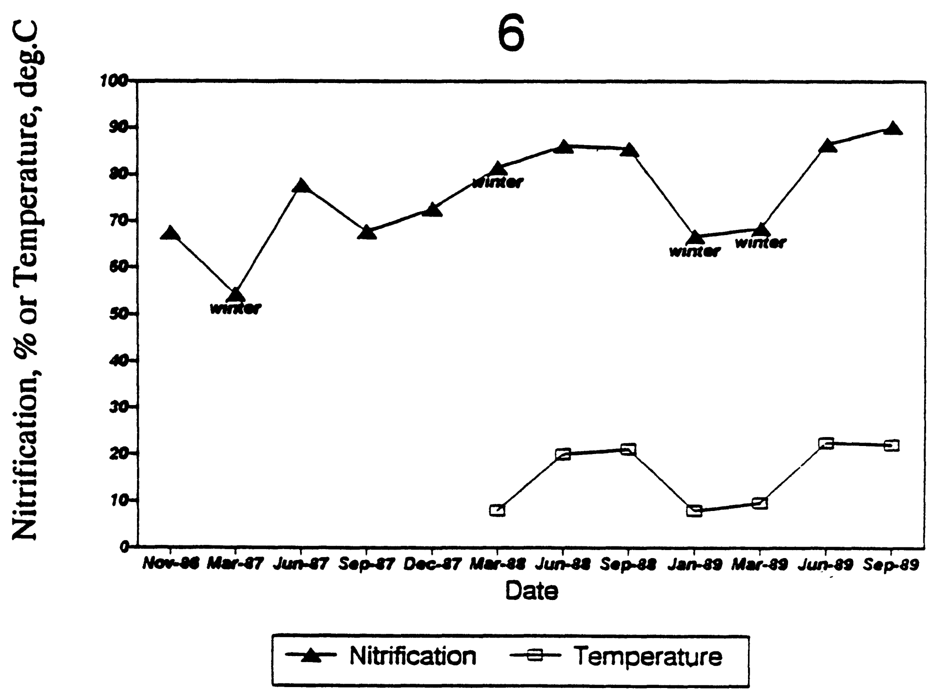




Appendix 6. continued.





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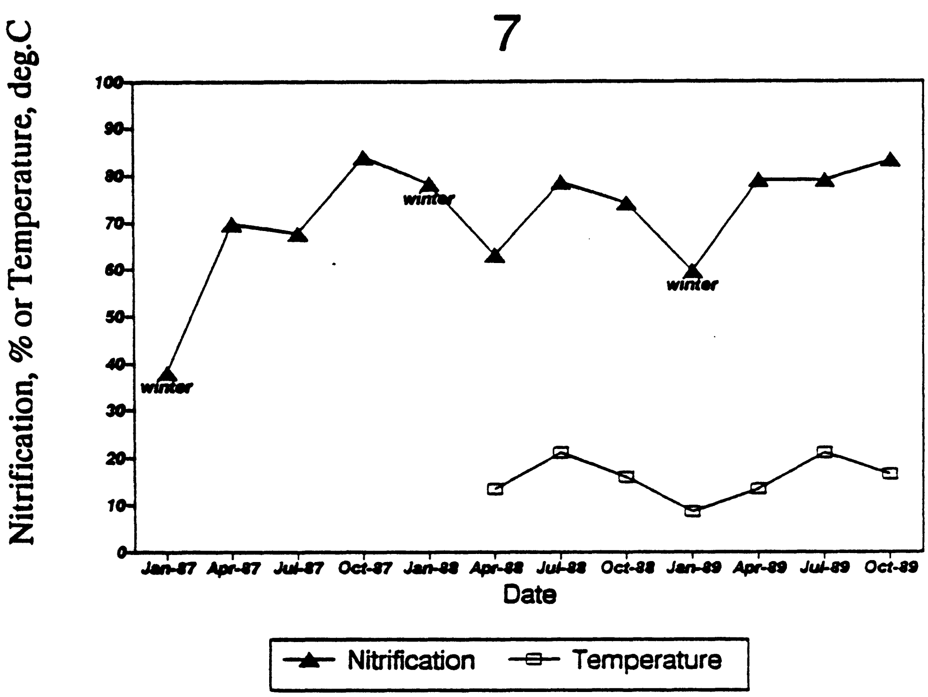

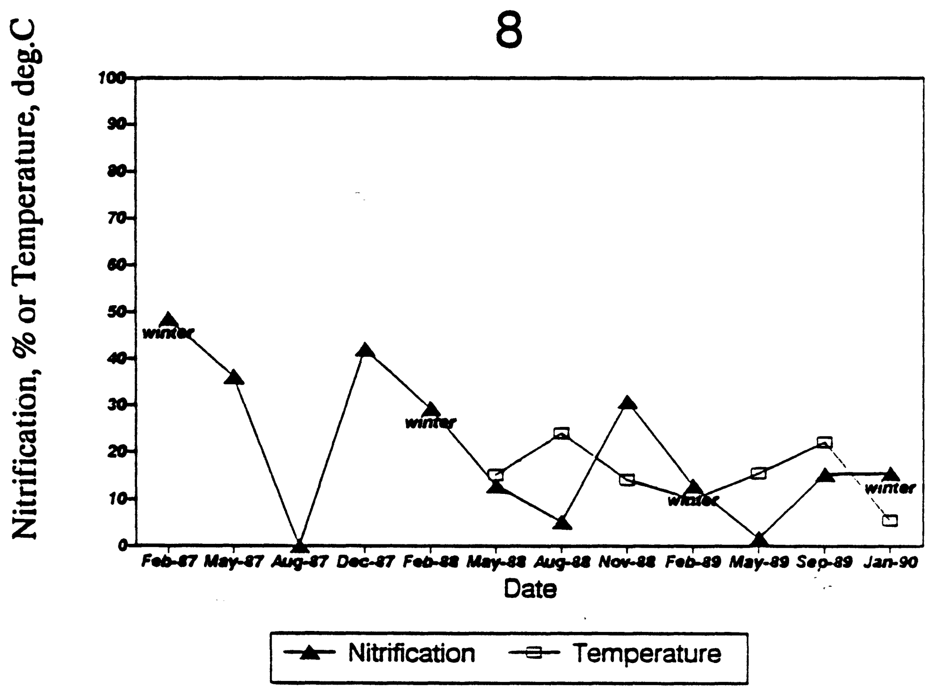

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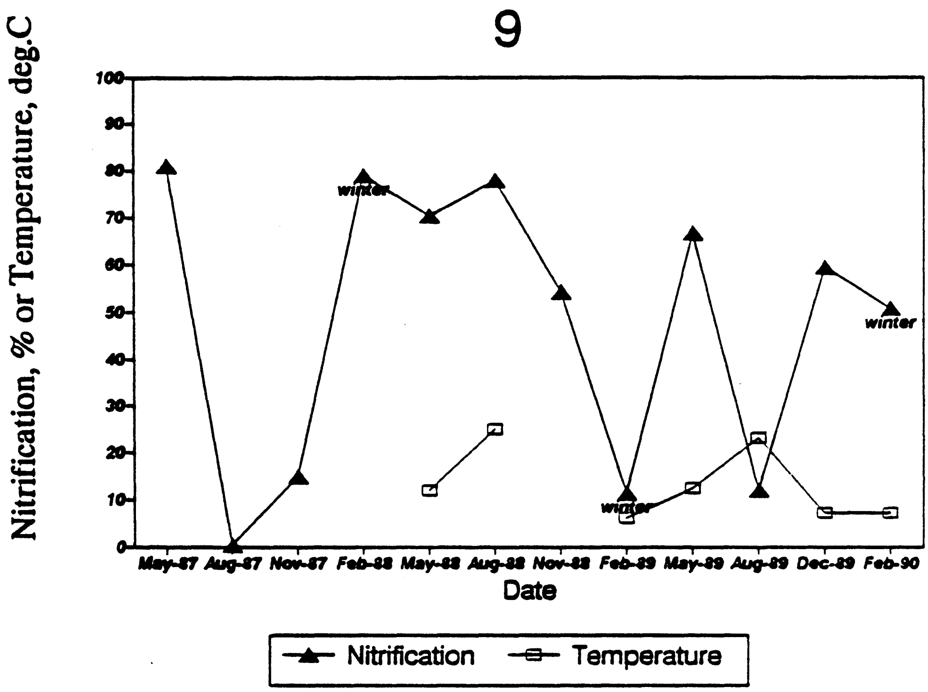
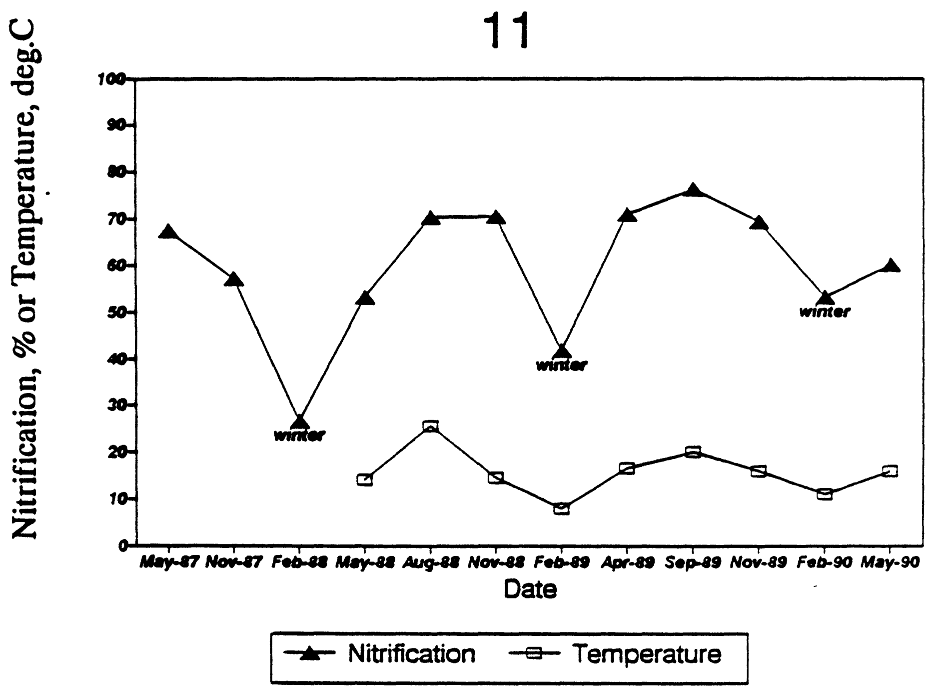
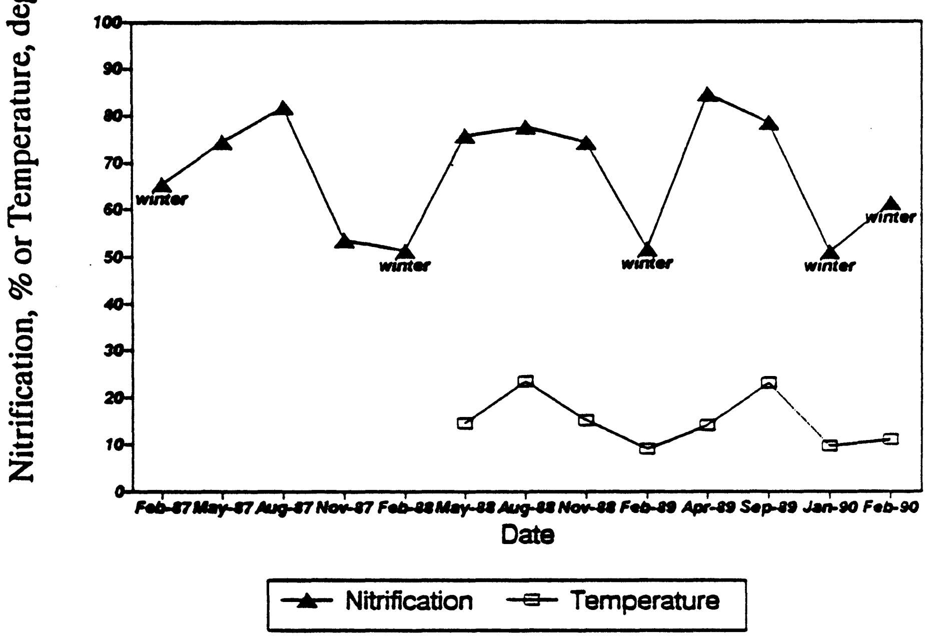




Appendix 6. continued.

12



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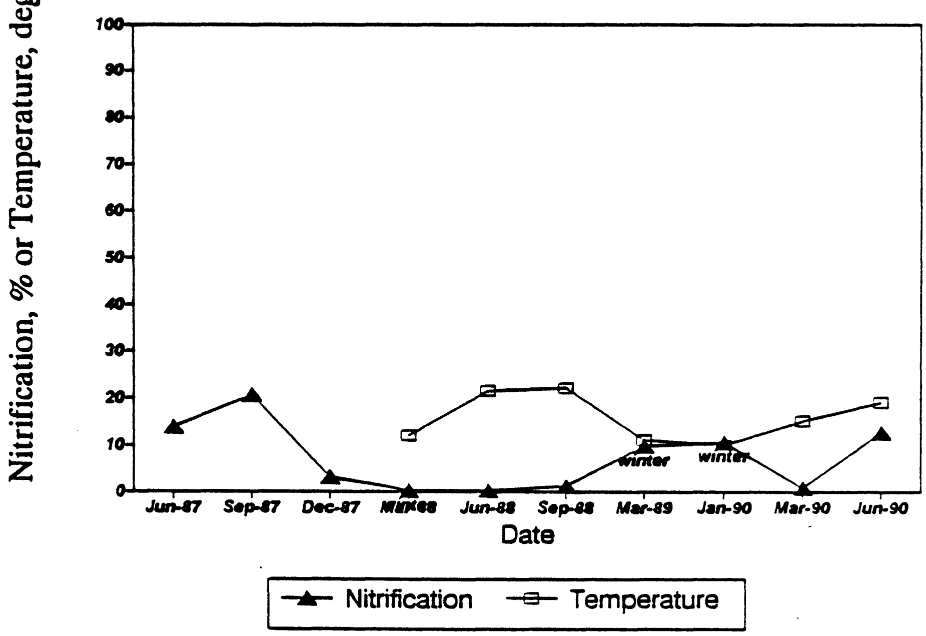

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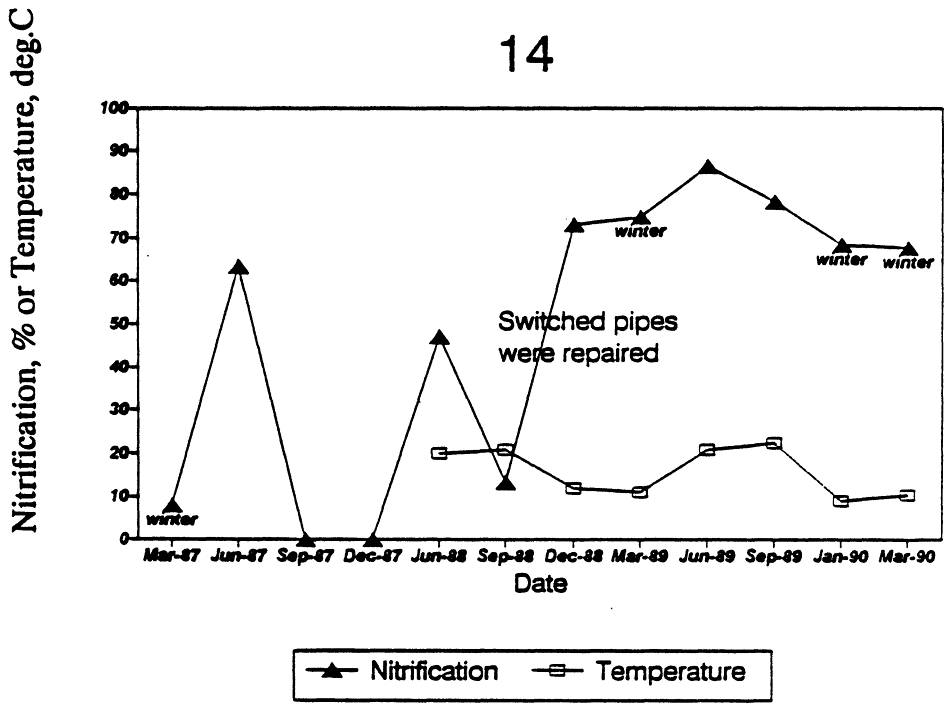

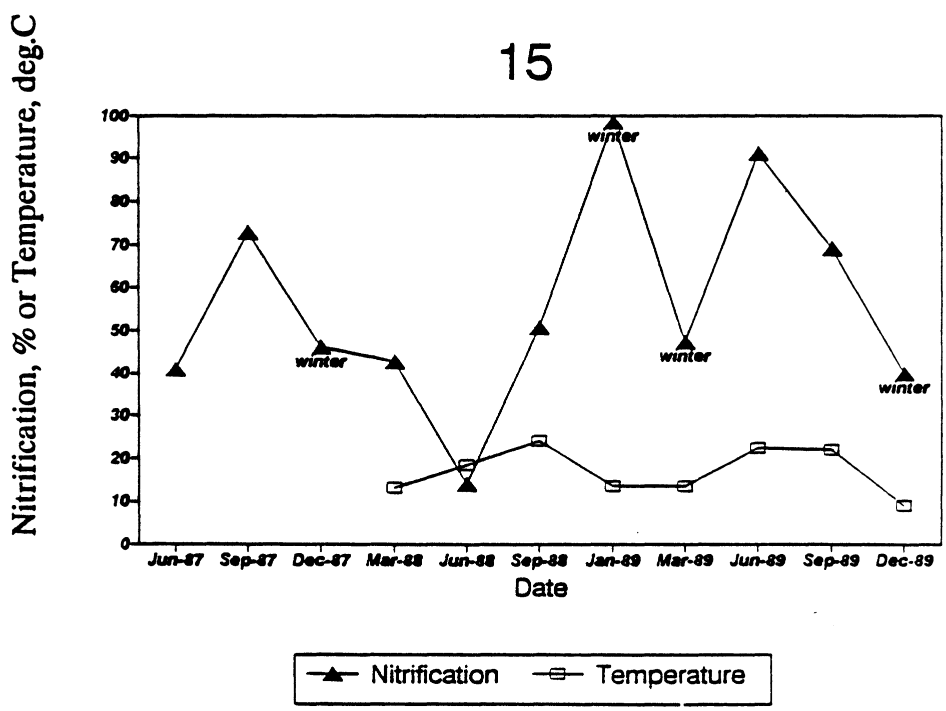

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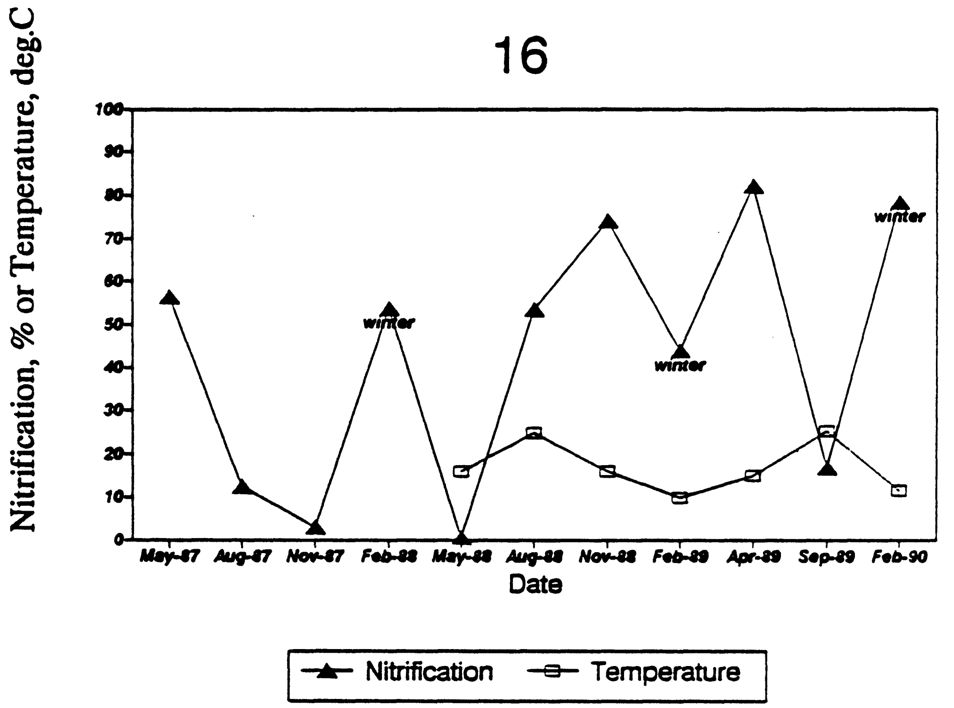

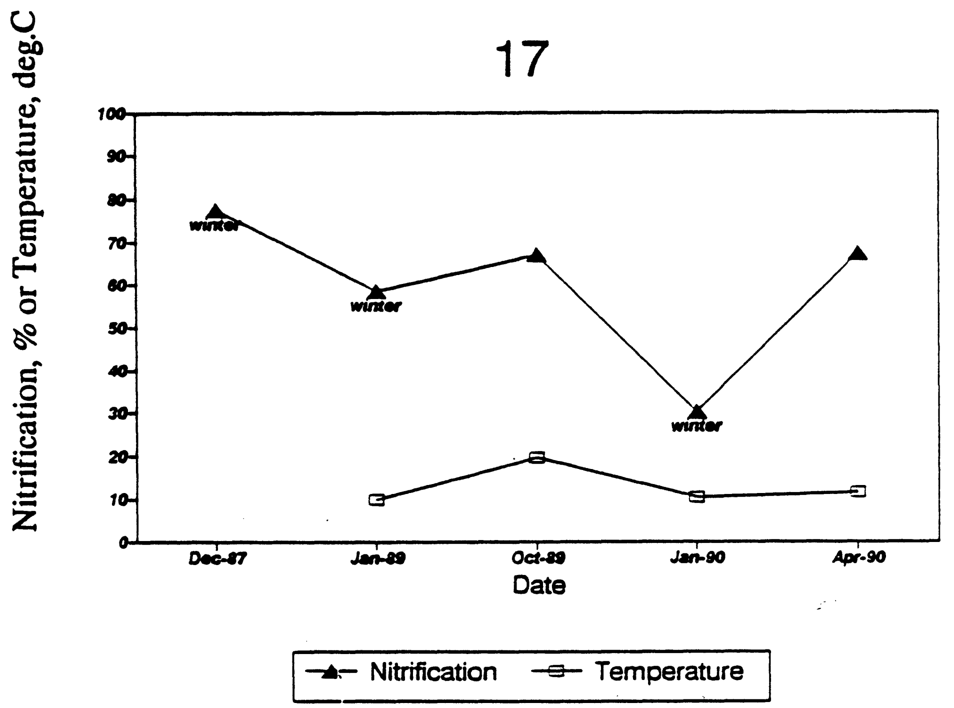

Appendix 6. continued.