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Field Evaluation of Nitrogen Removal from Septic Systems for  
Coastal Communities 35 pp

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Narragansett Bay Estuary Program

# Current Report

The Narragansett Bay Project

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FINAL PROJECT REPORT

FOR

FIELD EVALUATION OF NITROGEN REMOVAL  
SEPTIC SYSTEMS FOR COASTAL COMMUNITIES

PREPARED BY

THE DEPARTMENT OF NATURAL RESOURCES SCIENCE  
UNIVERSITY OF RHODE ISLAND

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PREPARED FOR

U.S. ENVIRONMENTAL PROTECTION AGENCY

REGION 1

NARRAGANSETT BAY PROJECT

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the U.S. Environmental Protection Agency and  
the R.I. Department of Environmental Management.



## FOREWORD

The United States Congress created the National Estuary Program in 1984, citing its concern for the "health and ecological integrity" of the nation's estuaries and estuarine resources. Narragansett Bay was selected for inclusion in the National Estuary Program in 1984 and designated an "estuary of national significance" in 1988. The Narragansett Bay Project (NBP) was established in 1985. Under the joint sponsorship of the U.S. Environmental Protection Agency and the Rhode Island Department of Environmental Management, the NBP's mandate is to direct a five-year program of research and planning focussed on managing Narragansett Bay and its resources for future generations. The NBP will develop a comprehensive management plan by December, 1990, which will recommend actions to improve and protect the Bay and its natural resources.

The NBP has established the following seven priority issues for Narragansett Bay:

- \* management of fisheries
- \* nutrients and potential for eutrophication
- \* impacts of toxic contaminants
- \* health and abundance of living resources
- \* health risk to consumers of contaminated seafood
- \* land-based impacts on water quality
- \* recreational uses

The NBP is taking an ecosystem approach to address these problems and has funded research that will help to improve our understanding of various aspects of these priority problems. The Project is also working to expand and coordinate existing programs among state agencies, governmental institutions, and academic researchers in order to apply research findings to the practical needs of managing the Bay and improving the environmental quality of its watershed.

This report represents the technical results of an investigation performed for the Narragansett Bay Project. The information in this document has been funded wholly or in part by the United States Environmental Protection Agency under assistance agreement #CX812768 to the Rhode Island Department of Environmental Management. It has been subject to the Agency's and the Narragansett Bay Project's peer and administrative review and has been accepted for publication by the Management Committee of the Narragansett Bay Project. The results and conclusions contained herein are those of the author(s), and do not necessarily represent the views or recommendations of the NBP. Final recommendations for management actions will be based upon the results of this and other investigations.

## EXECUTIVE SUMMARY

Substantial leaching of nitrate-nitrogen from conventionally designed on-site sewage disposal systems has been shown to threaten the water quality of groundwater and coastal estuaries in unsewered areas of the United States. The RUCK system was developed as one type of nitrogen removal system for on-site sewage disposal. RUCK systems have been installed at homes in several locations in the northeastern United States, although rigorous field testing of the systems has been limited. In Rhode Island, the Rhode Island Coastal Resources Management Council (CRMC) required the installation and monitoring of RUCK systems in selected shoreline homes of the Foster Cove region of Charlestown, Rhode Island. The goal of the research presented in this report was to provide much-needed baseline information on the performance of these full-scale RUCK systems under field conditions found in coastal Rhode Island. This information will be useful to state and local regulators responsible for permitting on-site sewage disposal system installation in sensitive coastal areas.

The RUCK system is designed to achieve nitrogen removal through the processes of nitrification followed by denitrification. Located after the septic tank, a buried sand filter provides the environment for nitrification, followed by a buried rock tank which provides the environment for denitrification. Greywater, a portion of the household wastestream including either kitchen and laundry wastewaters or all non-toilet wastewaters, is used as a carbon source for denitrification in the rock tank. Final disposal of rock tank effluent is in a conventional soil absorption field.

The specific objectives of the study were: (1) to evaluate the nitrogen removal performance of 2 RUCK systems (Systems D and K) used on a yearly basis in Charlestown, Rhode Island; and (2) to characterize greywater as a carbon

source for the denitrification process. This study also permitted initial comparisons between the performance of the Foster Cove RUCK systems and RUCK systems being used elsewhere in the northeastern United States.

Systems D and K at Foster Cove had average total-nitrogen (total-N) removal rates of 54% and 29%, respectively, at the point of discharge to the soil absorption field. Total-N concentrations in the rock tank effluent at that point of discharge were 30.5 mg/L for System D and 53.3 mg/L for System K. The incomplete total-N removal observed for the systems appeared to be a function of: (1) incomplete nitrification in the sand filters of both systems (average of 57-58%) which introduced total Kjeldahl nitrogen (TKN, ammonium-N + nitrate-N) into the rock tanks; (2) elevated greywater TKN concentrations in both systems (16-27 mg/L); and (3) incomplete denitrification in the rock tank of System K (average of 62%). Any TKN present in the wastestream when it entered the rock tank, either from the carbon source or from incomplete nitrification in the sand filter, was not denitrified in the rock tank and had the potential to be later nitrified in the soil absorption trench.

When comparing the results from the Foster Cove study to a replicated field study at U.R.I. and to preliminary results from a RUCK system study in New Jersey, a wide variability in system performance was observed. Average nitrification rates and total-N concentrations in rock tank effluent ranged from 7-82% and 10-53 mg/L, respectively. Denitrification was 100% in almost systems, with System K at Foster Cove one of the only full-scale systems which did not consistently achieve 100% denitrification. One reason for the incomplete denitrification observed in System K may have been that plumbing at System K did not meet 1989 RUCK specifications; greywater consisted of only kitchen and laundry wastewaters rather than all non-toilet wastewaters.

Further testing of RUCK systems is recommended to firmly establish the

nitrogen removal capacity of RUCK systems in Rhode Island. Long term studies are also needed to assess the nitrification efficiency and clogging potential of the buried RUCK sand filters as they mature. New designs for the nitrification component of the system may be warranted since incomplete nitrification was observed routinely at all Rhode Island systems.

## INTRODUCTION

On-site sewage disposal systems are used by approximately 1/3 of all homes in the United States as the method of treating and disposing of household wastewaters (Canter and Knox, 1985). Conventionally designed on-site sewage disposal systems consist of a buried septic tank followed by a subsurface soil absorption system. Such systems have been shown to be major sources of non-point source nitrogen inputs to groundwater and surface waters (Miller, 1975; Koppleman, 1978; DeWalle and Schaff, 1980; Ritter and Chirnside, 1984). Nitrogen inputs to coastal ponds and estuaries may promote increased eutrophication (Ryther and Dunstan, 1971; Harlin and Thorne-Miller, 1981), while inputs to shallow drinking water sources can raise nitrate-nitrogen ( $\text{NO}_3^-$ -N) concentrations above the 10 mg/L Federal drinking water standard (Preul, 1966; Walker et al., 1973; USEPA, 1976).

Conventional on-site sewage disposal systems are not specifically designed to promote nitrogen removal processes. Effluent leaving the septic tank contains nitrogen primarily as total Kjeldahl nitrogen (TKN, ammonium-nitrogen ( $\text{NH}_4^+$ -N) + organic-nitrogen). Once in the aerobic soil absorption system, the TKN can either be retained in the "crust" zone by sorption or filtration mechanisms or be rapidly oxidized to  $\text{NO}_3^-$ -N (Preul, 1966; Preul and Schroepfer, 1968; Walker et al., 1973a; Viraraghavan and Warnock, 1976; Andreoli et al., 1979). Because  $\text{NO}_3^-$ -N is a soluble anion, it is not affected by the cation exchange complex of the soil, but rather leaches rapidly through the soil environment to the groundwater and nearby surface waters (Preul and Schroepfer, 1968; Walker et al., 1973b). To maintain high water quality in unsewered areas experiencing heavy development pressures, innovative nitrogen removal systems need to be investigated for household wastewater disposal.

Several different innovative designs for nitrogen removal systems have been

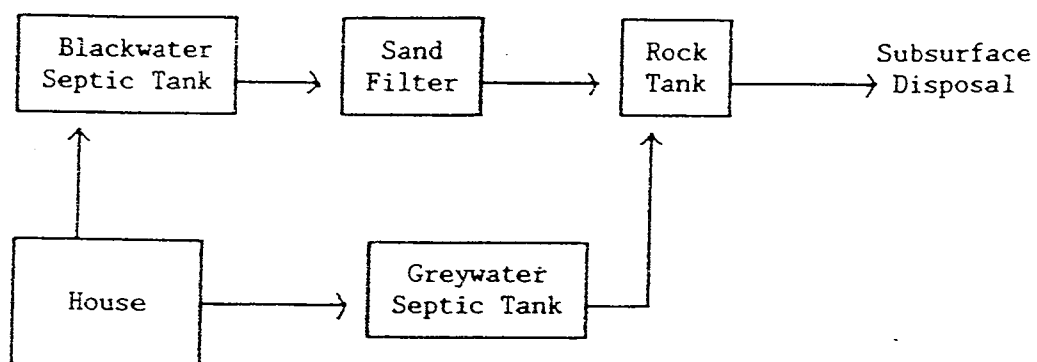
developed to date. These systems were designed to achieve nitrogen removal through the processes of nitrification followed by denitrification. With nitrification,  $\text{NH}_4^+\text{-N}$  is oxidized to  $\text{NO}_3^-\text{-N}$  under aerobic conditions; with denitrification, the  $\text{NO}_3^-\text{-N}$  is subsequently reduced to nitrogen gases under anaerobic conditions with the provision of a supplemental carbon source for the denitrifying bacteria. Total nitrogen (total-N) removal for an on-site sewage disposal system can be defined as the decrease in total-N which occurs between septic tank effluent and the point of discharge for the system. Any TKN present in the wastestream when it enters the anaerobic environment, either from the carbon source or from incomplete nitrification in the aerobic environment, will not be denitrified in the anaerobic zone and has the potential to be later nitrified in the soil absorption trench. The degree of denitrification in the anaerobic environment, the degree of nitrification in the aerobic environment and the presence of TKN in the carbon source are all factors which can affect the overall nitrogen removal of an on-site sewage disposal system.

The RUCK system was developed as one type of nitrogen removal system for on-site sewage disposal (Laak et al., 1981; Laak, 1982). In the RUCK system, the designed nitrification and denitrification components are a buried sand filter and a buried upflow rock tank, respectively (Figure 1). These two components are spatially located between the septic tank and the soil absorption field of a conventional on-site sewage disposal system. Studies have shown that measurable amounts of total-N removal can occur in conventional systems, occurring primarily in the soil absorption field (Andreoli et al., 1979; Lamb et al., 1988). In comparison with a conventional on-site sewage disposal system, the additional total-N removal provided by the RUCK systems occurs in the nitrification and denitrification components added between the septic tank and the soil absorption field.

In the RUCK system, the carbon source for denitrification is provided by



FIGURE 1. RUCK SYSTEM SCHEMATIC



greywater, a portion of the household wastestream. Special plumbing is required within the house to separate the total wastestream into greywater and blackwater flows. The classification of greywater has varied to include all non-toilet wastes in some households and only kitchen and laundry wastes in others, with blackwater representing the remaining portion of the wastestream. To assess the amount of carbon necessary for denitrification, the ratio of carbon to  $\text{NO}_3^-$ -N ( $\text{C}:\text{NO}_3^-$ -N) is typically used. It is generally suggested that ratios of 1:1 to 3:1 are necessary for optimal denitrification (Focht and Chang, 1975; Laak, 1982), although this may vary somewhat with the type and biological availability of the carbon source used.

RUCK systems have been installed at homes at several locations in the northeastern United States. The systems can be passive, gravity-feed systems or may need to incorporate a pump depending on site conditions. In situations where gravity-feed designs can be used, the systems are designed to require no additional homeowner involvement in the wastewater treatment process beyond routine septic tank pumping. Because RUCK system technology is still relatively new, however, even gravity-feed systems may require additional monitoring and maintenance of components to ensure proper system performance.

Rigorous field testing of RUCK systems has been limited. Preliminary work in Connecticut indicated that total-N removal rates of 71-81% could be achieved with the RUCK system, although the results were reported on only several installations (Laak et al., 1981; Laak, 1982). Sand filters achieved an average of 50-80% nitrification in these studies, while rock tanks achieved 84-97% denitrification with  $\text{C}:\text{NO}_3^-$ -N ratios of 0.7:1 or greater. A more comprehensive study of approximately 20 RUCK systems is currently underway in the Pinelands of New Jersey, where systems are sampled on a quarterly basis (Pinelands Commission, personal communication). A controlled, replicated field evaluation of the RUCK system in comparison with a conventional on-site sewage disposal

system was undertaken at the Department of Natural Resources Science at the University of Rhode Island (U.R.I.). One-fifth scale replicates of both types of systems were monitored for two years. Within the past several years RUCK systems have also been installed in the Foster Cove section of Charlestown, Rhode Island, although little field monitoring of the systems had occurred prior to this project.

The research presented in this report was undertaken to provide much-needed baseline information on the performance of full-scale RUCK on-site sewage disposal systems under field conditions found in coastal Rhode Island. This information will be useful to state and local regulators responsible for permitting on-site sewage disposal system installation in sensitive coastal areas. The specific objectives of the study were: (1) to evaluate the nitrogen removal performance of RUCK systems used on a yearly basis in Charlestown, Rhode Island; and (2) to characterize greywater as a carbon source for the denitrification process. This study permits initial comparisons between the performance of Rhode Island RUCK systems to RUCK systems being used elsewhere in the northeastern United States. No evaluation was performed of the fate and transport of nitrogen discharged into the environment by either RUCK or conventional systems. However, the results of this study should aid in such ecosystem scale studies.

#### SITE LOCATION

The research site was located in the Foster Cove section of Charlestown, Rhode Island. Because of a concern for both drinking water and surface water quality in the Foster Cove area, the Rhode Island Coastal Resources Management Council (CRMC) required the installation and monitoring of RUCK systems in

selected shoreline homes in this sensitive area. The CRMC has specifically stated the need for more information on denitrification systems for use in on-site sewage disposal (Olsen and Lee, 1984). To date there are eight homes which utilize RUCK systems in the Foster Cove area, although only two of the homes are primarily used on an annual basis. The Department of Natural Resources Science at the University of Rhode Island received approval to access and sample the RUCK systems through consent agreements between the homeowners and the Rhode Island Coastal Resources Management Council.

The soils in the Foster Cove area are coarse-silty over sandy or sandy-skeletal, mixed, mesic Aquic or Typic Dystrochrepts, primarily of the Tisbury and Enfield soil series (Rector, 1981). These moderately well-drained and well-drained soils are typical of southern New England coastal outwash soils and are often associated with unconfined aquifers exhibiting high transmissivities. All homes in the Foster Cove area were located on lots adjacent to either the main body of a coastal pond, Ninigret Pond, or to a poorly flushed cove of Ninigret Pond called Foster Cove.

#### METHODS

Because the dynamics of on-site sewage disposal systems can change when they are not used on a continual basis, only the two systems in full-time use were sampled in this study. The full-scale RUCK systems will be referred to as System D and System K in this report. Both Systems D and K were constructed according to design criteria established by Laak (Laak et al., 1981; Laak, 1985; Laak, 1986) and with the supervision and approval of the licensed RUCK system engineer in Rhode Island.

System D was installed at a six person home (2 adults and 4 children). The

house had 2.5 bathrooms, with 1 tub and 1 shower. All 3 toilets were low-flush water saving toilets (3.5 gallons/flush). Based on conversations with the homeowner, approximately 4-5 loads of laundry were done each week. The kitchen was also equipped with a garbage grinder, although the homeowner reported that it was seldom used. Based on engineering records and visual observations, the house was plumbed such that the greywater portion of the flow represented all non-toilet wastes from the household with blackwater representing only the toilet wastes. According to the U.S. EPA (1980) this flow separation would result in an average greywater:blackwater flow ratio of approximately 60%:40%, although the ratio may vary to as much as 80%:20%, due to low flush toilets and the amount and type of other water usage within the home.

System K was installed at a three person home (3 adults). There were 2 working bathrooms in the house, each with a tub or shower and a low-flush toilet with a water-saving device. Based on conversations with the homeowner, approximately 3-4 loads of laundry were done each week at the house. The kitchen did not have a garbage grinder. Engineering records for this system suggested the same type of flow separation as for System D. Visual observations suggested, however, that in fact the blackwater portion of the flow represented all bathroom wastes, with greywater representing only kitchen and laundry wastes. This type of flow separation would result in an average greywater:blackwater flow ratio of approximately 40%:60%, with a range of 35%:65% to 60%:40%, again depending on the type and distribution of water usage within the home (U.S. EPA, 1980).

Although the installation of flow meters was required by the CRMC for other RUCK systems at Foster Cove, the installation of meters was not required at either System D or System K. Without flow meters it was not possible to directly monitor the actual blackwater and greywater flow ratios for the two systems. In this report, the average greywater:blackwater flow ratio for each

system was estimated based on the published U.S. EPA ratios mentioned above, conversations with the homeowners regarding water usage, and the average total-N concentration expected from a typical household. Total-N concentrations from a household range from 30-100 mg/L (U.S. EPA, 1980), although most studies report concentrations of 50-80 mg/L (Andreoli et al., 1979; Harkin et al., 1979; Canter and Knox, 1985) as typical. Using total-N concentrations from greywater and blackwater in Systems D and K and the range of flow ratios suggested by the U.S. EPA, the following estimated greywater:blackwater flow ratios were adopted for the two systems: 80%:20% for System D and 60%:40% for System K. Using these ratios, the concentration of total-N leaving the house generally ranged between 60-80 mg/L for both systems. The ratio adopted for each system is on the high end of the range suggested by the U.S. EPA, which might be expected due to the use of low-flush toilets in both households.

Samples were collected on a triweekly basis from each system when the homes were occupied. System D was sampled from June 1988 to November 1988 and January 1989 to May 1989 and System K was sampled from November 1988 to May 1989. Each sampling period, a 250 ml sample was taken in a polyethylene bottle of blackwater septic tank effluent, greywater septic tank effluent, sand filter effluent and rock tank effluent. Temperature (Method 170.1) and pH (Method 150.1) were determined immediately after samples were collected (U.S. EPA, 1979). An additional 250 ml sample of greywater septic tank effluent was taken in a glass bottle for subsequent total organic carbon (TOC) analysis.

After collection, all samples were brought back to the laboratory. TOC samples were acidified with  $H_2SO_4$  and stored at 4°C. Analysis was conducted by a New Hampshire state certified laboratory, Resource Analysts, Inc., Hampton, NH (Method 415.1, U.S. EPA, 1979). Alkalinity measurements were done on the samples stored in polyethylene bottles within 6 hours of sample collection (Method 310.1, U.S. EPA, 1979). A 100 ml portion of each sample was then

acidified with  $\text{H}_2\text{SO}_4$  and stored at  $4^\circ\text{C}$  for subsequent TKN analysis. TKN analysis was conducted within 4 weeks of sample collection by the block digester method (Eastin, 1978; Method 351.4, U.S. EPA, 1979) followed by  $\text{NH}_4^+\text{-N}$  determination by the colorimetric salicylate-hypochlorite method (Bower and Holm-Hansen, 1980). The unacidified portion of each sample was filtered and stored at  $4^\circ\text{C}$ . Nitrate-nitrogen and nitrite-nitrogen ( $\text{NO}_3^-\text{-N} + \text{NO}_2^{2-}\text{-N}$ ) and  $\text{Cl}^-$  analyses were performed on the filtered sample by ion chromatography within 2 days of sample collection (Method 300, U.S. EPA, 1984). In this report,  $\text{NO}_3^-\text{-N} + \text{NO}_2^{2-}\text{-N}$  will be reported as  $\text{NO}_3^-\text{-N}$ .

Precision and accuracy were routinely assessed for all laboratory analyses. Precision was measured as the percent difference between duplicate sample analyses. Duplicate analyses were performed on at least 10% of samples from each batch. If duplicate analyses were not within 5% of each other, the analyses conducted within the batch were repeated. Accuracy was measured as percent recovery of known standards. Standards were made from ACS standard grade reagents. If recoveries were not within 90-110%, analyses conducted within the batch were repeated. In addition to routine analysis of standards, the Department of Natural Resources Science participated in two Water Pollution Evaluation Studies conducted by the U.S. EPA during the study period.

In addition to the laboratory analyses performed on the samples from Foster Cove, TOC analyses were also performed on greywater septic tank effluent samples from 15 of the RUCK systems in the New Jersey Pinelands study and from the home supplying greywater for the replicated field study at U.R.I. These analyses were conducted to aid in the characterization of greywater as a carbon source for denitrification. Greywater TOC data from 1987 for the New Jersey and U.R.I. field systems were also reviewed. Nitrogen removal results of the replicated U.R.I. study and unpublished, preliminary information as of June 1989 on the nitrogen removal performance of the RUCK systems in New Jersey were reviewed to

provide a comparison for the results generated in the Foster Cove study.

## RESULTS AND DISCUSSION

The performance of the RUCK systems at Foster Cove will be discussed in terms of: a) the % nitrification and total-N removal in the sand filters; b) the % denitrification in the rock tanks; and c) the % total-N removal for each system at the point of discharge from the rock tank. Where applicable, the Foster Cove results will be directly compared to results from the replicated U.R.I. study and to preliminary results as of June 1989 from the New Jersey study.

### NITROGEN DYNAMICS IN THE SAND FILTERS

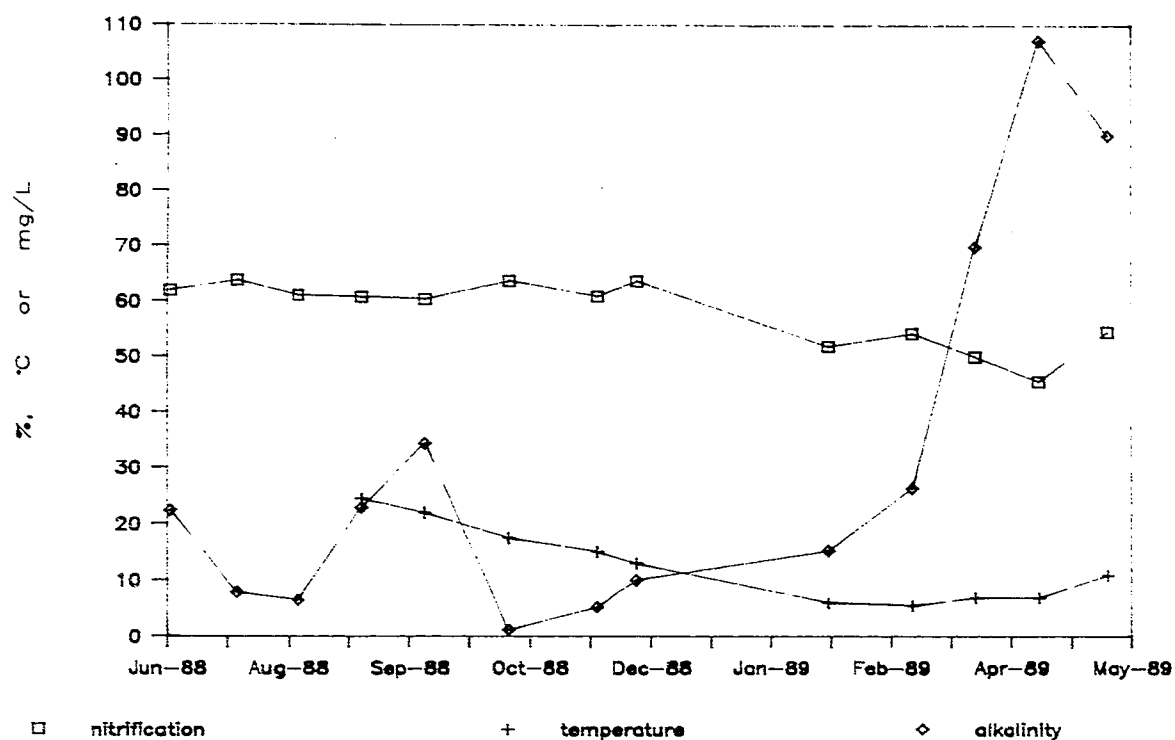
Nitrification in the sand filters was calculated as the percentage of sand filter effluent total-N that was in the  $\text{NO}_3^-$ -N form. Total-N removal within the sand filters was calculated as the percentage decrease in total-N between blackwater septic tank effluent and sand filter effluent. Both processes affect the overall total-N removal for the on-site sewage disposal system.

Nitrification. The mean % sand filter nitrification for the study period in System D and System K was 58% (S.E.=1.6%) and 57% (S.E.=2.4%), respectively. The literature suggests that below 10-15°C, temperature can have a significant impact on nitrification rates (McCarty et al., 1969; Dawson and Murphy, 1972; Stanford et al., 1975; Focht and Chang, 1975; Stanier and Adelberg, 1976). In this study, nitrification rates did not appear to be markedly influenced by the decrease in temperature during the winter months (Figure 2). In System D,

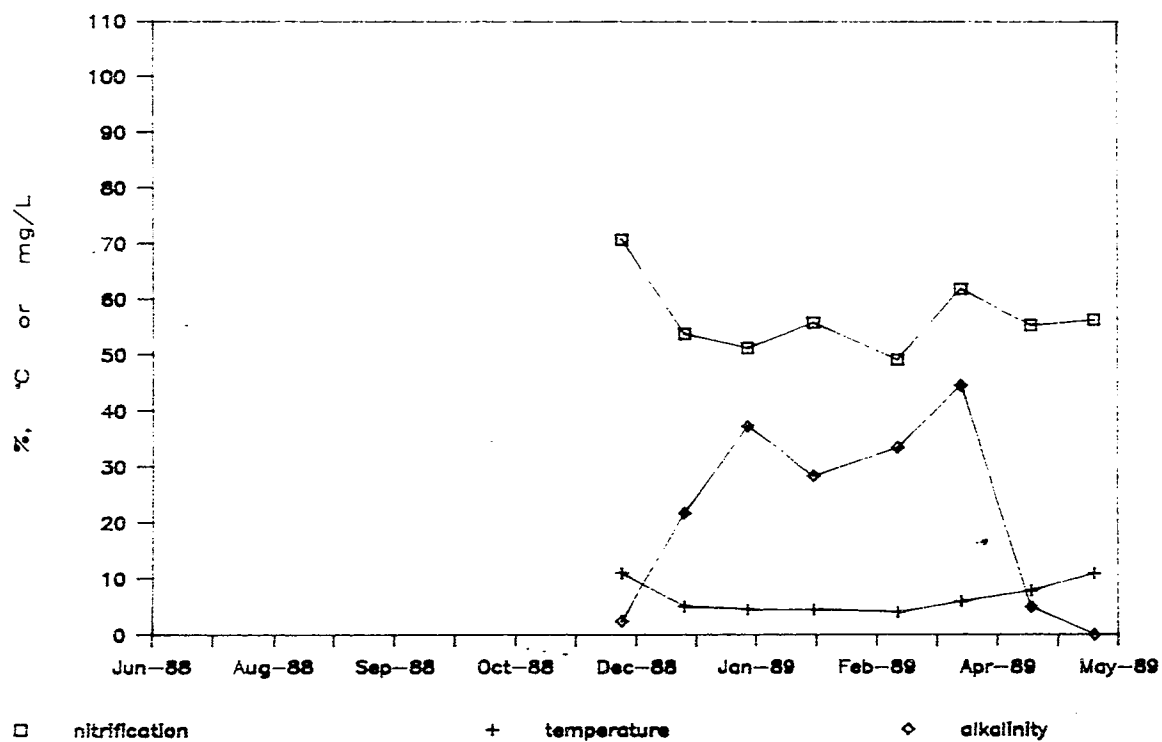


Figure 2. Nitrification (%), Temperature ( $^{\circ}\text{C}$ ), and Alkalinity (mg/L) of Sand Filter Effluent.

### SYSTEM D



### SYSTEM K



nitrification ranged from 46-64% during the study period, with nitrification rates decreasing only slightly in the winter months. There did appear to be a dramatic decrease in nitrification rates in System K between November and December, but nitrification only marginally increased as the temperature rose during spring sampling. Additional summer sampling would be necessary for a more accurate indication of nitrification patterns in System K. Nitrification rates ranged from 49-71% in System K during the 6 months it was sampled.

In the U.R.I. replicated study, RUCK sand filters had an average nitrification of 69% (S.E.=0.9%) over the two year study period, with a range of 46-80%. Nitrification rates did appear to decrease slightly with decreased temperatures, but to a lesser degree than did nitrification rates in above-ground recirculating sand filters in the same study. Because the RUCK filters are buried filters, they are less exposed to temperature extremes than above-ground filters (Lamb et al., 1988). In the New Jersey study, preliminary nitrification results for 15 of the systems sampled indicated nitrification rates ranging from 7-82%. Twelve of these systems had average nitrification rates of greater than 50%, with a median value for the 12 systems of approximately 66-69%.

Alkalinity and pH are two other parameters which are often analyzed when assessing sand filter performance. During the process of nitrification, the pH of the effluent drops due to the production of  $H^+$  ions. To neutralize the  $H^+$  ions produced, approximately 7.14 mg of  $HCO_3^-$  alkalinity is required for every 1 mg of  $NH_4^+-N$  oxidized. If sufficient alkalinity is not available to neutralize the  $H^+$  produced, the pH of the system could drop below 5.5, at which point nitrification could be inhibited (Haug and McCarty, 1972; U.S. EPA, 1975).

During the two years of the replicated U.R.I. study there was an absence of alkalinity in sand filter effluent on all but three sampling dates. The average pH of sand filter effluent in these RUCK systems was 4.0, suggesting that

perhaps the depletion of alkalinity and subsequent decrease in pH may have been partially responsible for the lack of complete nitrification observed in the sand filters. Laak et al. (1981) and Laak (1982) observed the same depletion of alkalinity in other RUCK sand filters.

Alkalinity and pH did not appear to be limiting factors to sand filter nitrification in the Foster Cove study. In System D, alkalinity and pH in sand filter effluent ranged from 1-107 mg/L and 5.2-7.4, respectively. The pH of filter effluent dropped below 5.5 on only one sampling date with no apparent effect on nitrification. Neither pH or alkalinity exhibited seasonal trends or appeared to be related to the degree of nitrification in this system (Figure 2).

In System K, alkalinity and pH in sand filter effluent ranged from 0-45 mg/L and 4.6-6.8, respectively. The pH of filter effluent dropped below 5.5 on only the first and last sampling dates with no apparent effect on nitrification. Alkalinity of sand filter effluent in System K did appear to exhibit some seasonal variability (Figure 2), with alkalinity increasing in the cooler months and decreasing in the warmer months. As indicated previously, further summer data would be needed to more accurately assess the affect, if any, of decreased alkalinity and pH on % nitrification in System K over time.

The difference observed in sand filter alkalinity results for the two studies (Foster Cove and U.R.I.) may have been due in part to the differences in composition of the sand filter influent. At the U.R.I. study, the wasteflow into the sand filter was from the total wastestream (greywater + blackwater), with alkalinity of 200-300 mg/L. At Foster Cove, the influent was blackwater, which had an average alkalinity of 984 mg/L and 474 mg/L in Systems D and K, respectively. The greater buffering capacity of the blackwater probably accounted for the more neutral pH observed in the sand filters of Systems D and K at Foster Cove.

The results from the three different studies of RUCK systems indicates that

sand filter nitrification can be variable, ranging from approximately 10-80%, with the majority of systems between 50% and 80%. Temperature, alkalinity and pH may be partially responsible for the variability, although no consistent relationships between these factors and the rate of nitrification were observed. The fact that none of the sand filters had nitrification rates of 100% indicates that some TKN is being introduced into the rock tanks from the sand filter effluent. This TKN can be expected to pass unchanged through the rock tanks to be later nitrified in the soil environment while moving from the soil absorption trench. Therefore, the average 20-50% of the blackwater total-N in each system which is not nitrified in the sand filters limits total-N removal for the complete system, even if denitrification is 100% in the rock tanks. Based on information from New Jersey, nitrification rates of <50% may reflect problems with sand filter installation or design, such as clogging of the filter media or the improper placement of air pipes for filter ventilation. None of these problems were apparent at either the Foster Cove or U.R.I. sites.

Total-N removal in sand filters. Numerous researchers have observed that some removal of the total-N in septic tank effluent can occur in essentially aerobic environments, such as sand filters (Loudon et al., 1985; Otis, et al., 1975). The mean total-N removal for the sand filters in this study was 23% for both Systems D and K, with standard errors (S.E.) of 7.8% and 5.8%, respectively. Mean total-N removal in the U.R.I. RUCK sand filters was 7% (S.E.=1.1%).

Two possible nitrogen removal mechanisms in the sand filters could be ammonia ( $\text{NH}_3\text{-N}$ ) volatilization, and the release of gases associated with both nitrification and denitrification (Lance, 1972; Bremner and Blackmer, 1978; Tyler et al., 1978; Goreau et al., 1980; Rittman and Langeland, 1985). Ammonia volatilization, the conversion of  $\text{NH}_4^+\text{-N}$  to  $\text{NH}_3\text{-N}$  gas, becomes a possible removal mechanism at a pH of greater than 8.0-9.0. The average pH of blackwater

septic tank effluent for System D and System K was 8.11 and 8.43, respectively. The pH entering the sand filters in the two systems may have been high enough for  $\text{NH}_3\text{-N}$  volatilization to account for a portion of the total-N removal observed within the sand filters. The pH of the septic tank effluent entering the U.R.I. sand filters ranged from 7.0-7.5. Volatilization was probably not a major removal mechanism for these filters, perhaps accounting for the lower total-N removal observed as compared to the Foster Cove sand filters.

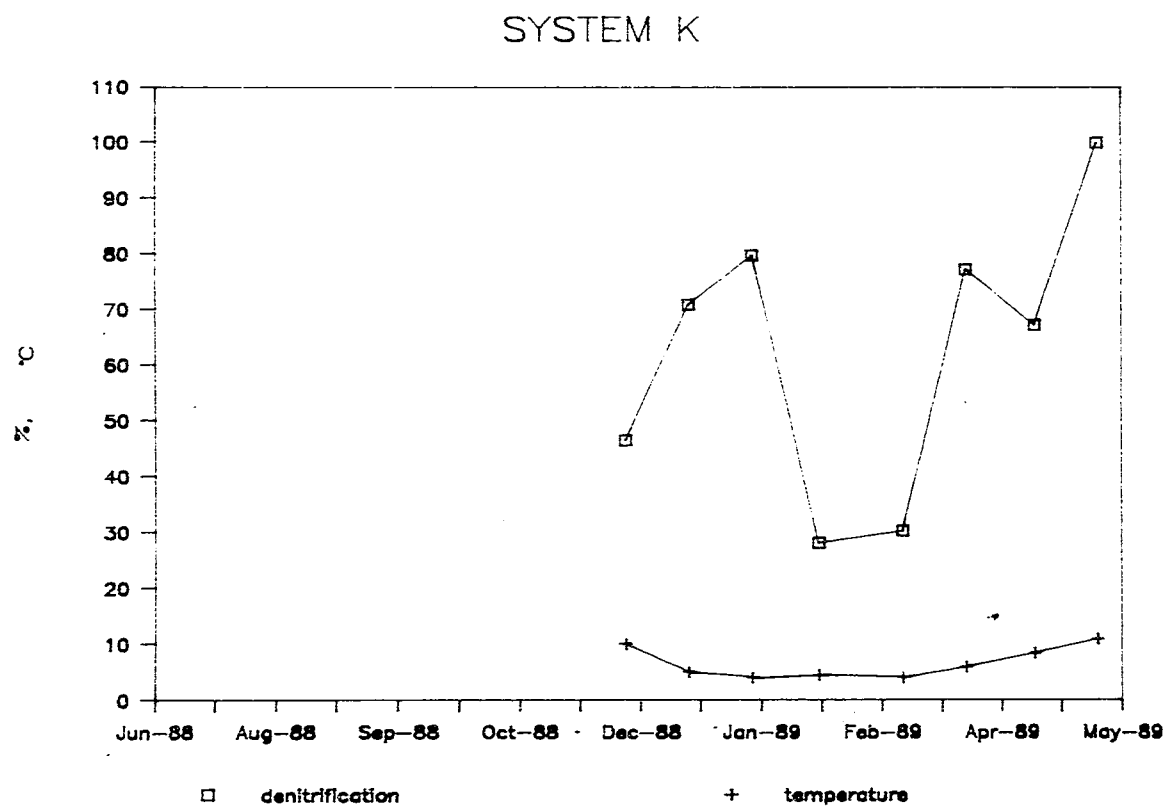
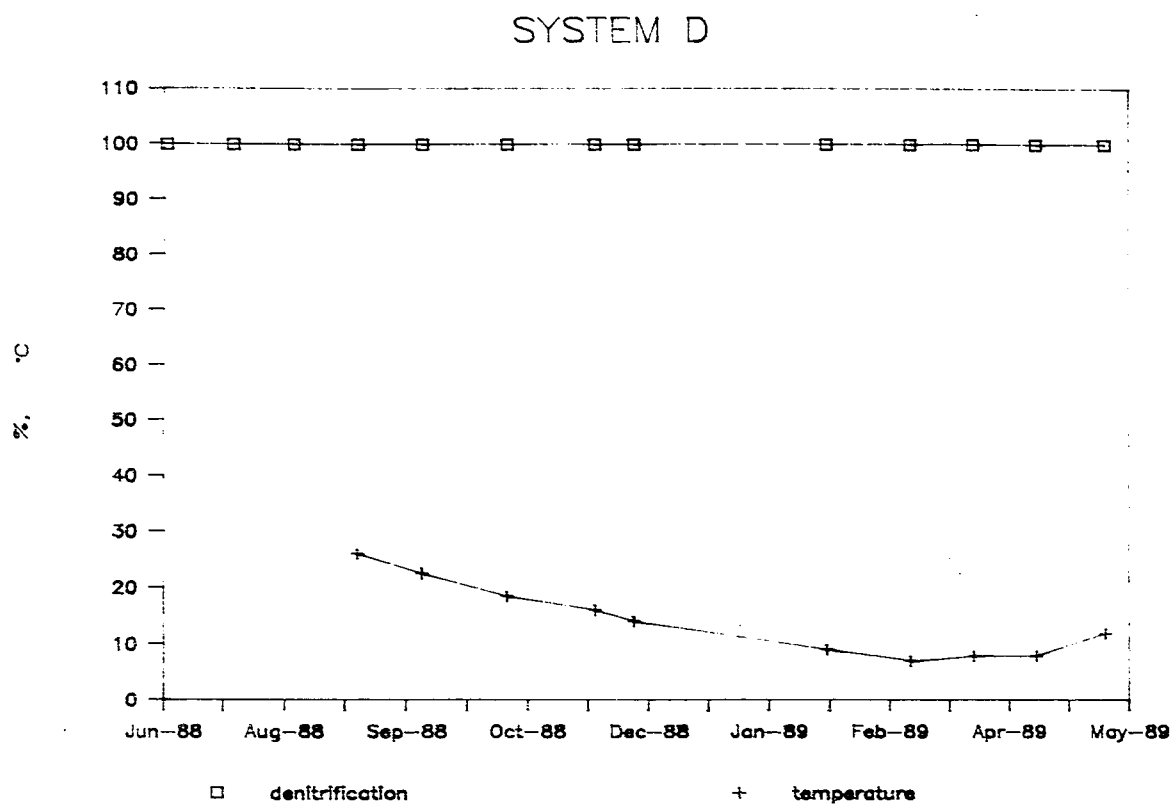
The release of nitrogen gases from sand filters due to the processes of nitrification and denitrification appears to be the most likely nitrogen removal mechanism in the sand filters. The gases released may be nitrous oxide ( $\text{N}_2\text{O}$ ) associated with nitrification (Bremner and Blackmer, 1978; Goreau et al., 1980) and  $\text{N}_2$  associated with denitrification. Although the sand filters were designed to function as aerobic environments, anaerobic microenvironments may have existed within the filters providing the environment necessary for denitrification (Rittman and Langeland, 1985).

#### ROCK TANK DYNAMICS

Rock tank denitrification was calculated as the percentage decrease in  $\text{NO}_3^- \text{-N}$  between effluent entering and leaving the rock tanks. Denitrification is dependent on the presence of an anaerobic environment and an adequate carbon source for the denitrifying bacteria. In the Foster Cove study, both systems used similarly designed anaerobic components, with slightly different carbon sources. In System D the carbon source was provided by greywater incorporating all non-toilet wastes; in System K the greywater carbon source consisted of only kitchen and laundry wastewater.

The denitrification rates for the two systems are shown in Figure 3. In

Figure 3. Denitrification (%) and Temperature (°C) in Rock Tank Effluent



System D, denitrification was 100% on all sampling dates. In System K the average denitrification was 62% (S.E.=9.0%), with a range of 28-100%.

Denitrification decreased in the winter months although further sampling would be necessary to accurately assess the seasonal affects on denitrification in this system. Based on the estimated greywater:blackwater flow ratios for the two systems the average C:NO<sub>3</sub><sup>-</sup>-N ratio in effluent entering the rock tank was 6.8:1 (wastewater ratio of 80%:20%) for System D and 5.2:1 (wastewater ratio of 60%:40%) for System K. In each system there was a wide variability in both the TOC concentrations in the greywater and in the C:NO<sub>3</sub><sup>-</sup>-N ratio in effluent entering the rock tank (Table I). All the NO<sub>3</sub><sup>-</sup>-N entering the rock tanks came from sand filter effluent, as no NO<sub>3</sub><sup>-</sup>-N was found in either greywater source.

Table I shows the TOC, C:NO<sub>3</sub><sup>-</sup>-N ratios and % denitrification data for the Foster Cove systems in comparison with data from the U.R.I. study. One greywater source was used in the U.R.I. study, although it was introduced to the rock tanks at 2 different strengths designed to mimic the situations where greywater represented only kitchen and laundry wastes (Experiment 1) and where greywater was composed of all non-toilet wastes (Experiment 2). The results presented in Table I indicate that there is a wide variability in carbon concentrations associated with greywater from different sources as well as from the same source. The resulting variability in C:NO<sub>3</sub><sup>-</sup>-N ratios observed is probably due to the typical range of water usage and activity (laundry loads, kitchen use, etc.) occurring in a household.

The systems in Experiment 1 at U.R.I. had the lowest average denitrification as well as the lowest range of C:NO<sub>3</sub><sup>-</sup>-N ratios, with ratios of less than 3.0 observed for all sampling dates. System D, System K and Experiment 2 at U.R.I. all had C:NO<sub>3</sub><sup>-</sup>-N ratios which were generally between 2-8, with a variety of associated denitrification rates. Based on these results, it was not possible to determine a definitive range of C:NO<sub>3</sub><sup>-</sup>-N ratios necessary for 100%

Table I. TOC, C:NO<sub>3</sub><sup>-</sup>-N Ratio and % Denitrification in Rock Tanks From RUCK Systems at Foster Cove, RI and the Replicated U.R.I. Study.

	TOC, mg/L		C:NO <sub>3</sub> ratio in rock tanks		Denitrification in rock tanks, %	
	$\bar{x}$ (S.E.) <sup>a</sup>	range <sub>b</sub> (n)	$\bar{x}$ (S.E.)	range (n)	$\bar{x}$ (S.E.)	range (n)
<u>Foster Cove</u>						
System D	157 (25.3)	69-310 (10)	6.8 (1.9)	1.9-22.7 <sup>c</sup> (10)	100 --	-- (10)
System K	216 (16.6)	170-280 (7)	5.2 (0.6)	2.9-7.3 (7)	62 (9.0)	28-100 (7)
<u>U.R.I. Study</u>						
	225 (19.4)	130-310 (8)				
Experiment 1			1.5 (0.4)	0.7-3.0 (6)	53 (5.1)	28-86 (10)
Experiment 2			4.7 (4.0)	2.2-5.8 (8)	88 (4.8)	50-100 <sup>d</sup> (10)

a) S.E. = standard error

b) n = # of observations

c) one date had ratio of 22.7, otherwise range was 1.9-8.2

d) 100% denitrification observed on all but first three sampling dates



denitrification. The results did suggest, however, that complete denitrification could be regularly achieved in systems using greywater as a carbon source if the greywater included all the non-toilet wastes from the household, such as in System D and Experiment 2 at U.R.I. The systems in which greywater included only kitchen and laundry wastes, System K and Experiment 1, did not show consistent denitrification.

Preliminary data to date from the RUCK systems in New Jersey indicates that 14 of the 15 systems sampled for greywater TOC concentrations had 100% denitrification in the rock tanks. The average TOC concentration for the 15 systems was 99 mg/L (S.E.=10.6 mg/L), with a range of 6.5-210 mg/L. It is interesting to note that, although the range of TOC concentrations for the New Jersey systems was generally lower than that observed for the systems described in Table 1, denitrification in the New Jersey systems was still generally 100% (Windisch, 1989). There was insufficient documentation of the plumbing at the houses to determine what was included as greywater and blackwater in these RUCK systems, or to determine average flow ratios and  $C:NO_3^-$ -N ratios.

In addition to TOC concentrations and the resultant  $C:NO_3^-$ -N ratios, the TKN in the carbon source also needs to be considered when assessing carbon sources for denitrification. In the Foster Cove systems, greywater constituted an average of 20% and 22% of the total-N in the wastestream from Systems D and K, respectively. The average TKN concentrations in greywater were 16.4 mg/L for System D and 27.1 mg/L for System K. The mass of TKN delivered to the rock tank through the greywater would depend on the percentage of the flow represented as greywater. Given the estimated flow ratios indicated above for the two systems, rock tank effluent would have an average total-N concentration of 13-16 mg/L due solely to the amount of TKN present in the greywater. The average TKN concentrations in greywater from the U.R.I. study and from the New Jersey systems were approximately 17 mg/L and 13 mg/L, respectively. The range in

concentrations for the 15 New Jersey systems was 5-35 mg/L (the 35 mg/L value was found in a commercial system), demonstrating again the variability in chemical characteristics of greywater.

#### TOTAL-N REMOVAL FOR EACH SYSTEM

To allow for comparisons with conventional systems, the evaluation of total-N removal will be described by: (a) the percent reduction in the mass of nitrogen occurring in a system between septic tank effluent and rock tank effluent; and (b) the total-N concentrations in rock tank effluent. The total-N removal observed for each system was affected in part by the degree of nitrification and total-N removal in the sand filter, the degree of denitrification in the rock tank and the amount of TKN introduced to the rock tank through greywater inputs.

The percent reduction in total-N in System D and System K averaged 54% (S.E.=2.6%) and 29% (S.E.=5.9%), respectively. The difference in % total-N removal between the two systems may have been due to the difference in rock tank denitrification rates and the differences in TKN concentrations in the greywater mentioned previously. The influence of denitrification on system total-N removal was also observed for Experiments 1 and 2 of the U.R.I. study; the systems in Experiment 2, where denitrification was 100%, had an average total-N removal of 52% (S.E.=3.0%) as compared to 45% (S.E.=3.0%) in Experiment 1.

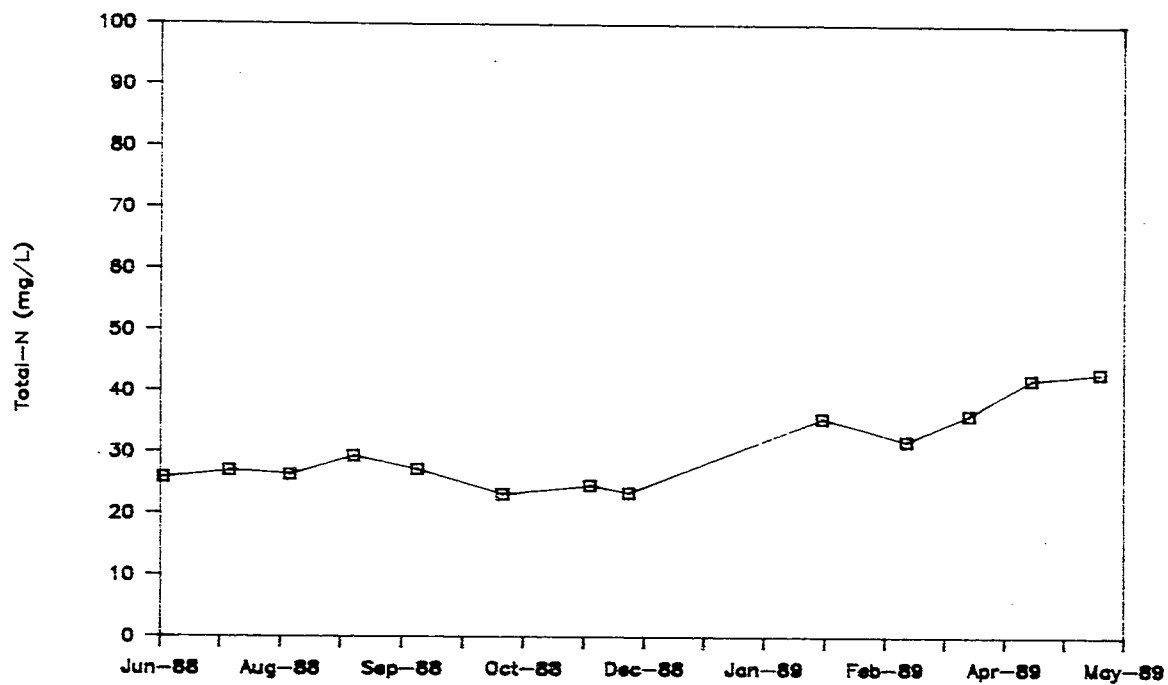
As with conventional on-site sewage disposal systems, some removal of total-N is expected to occur in the soil absorption field, which will increase the total-N removal of these RUCK systems. Several studies have determined the total-N removal rates associated with conventional on-site sewage disposal systems. The U.R.I. replicated study observed average total-N removal rates of

approximately 5% associated with the soil absorption field of a conventional system at a point 3 feet below the bottom of the field (Lamb et al., 1988). In a Long Island study, Andreoli et al. (1979) observed 36%-38% total-N removal in a conventional soil absorption field at depths of 2-4 feet beneath the field. In both systems, the soil absorption fields were constructed in the same type of coarse outwash sands and gravels as the Foster Cove systems.

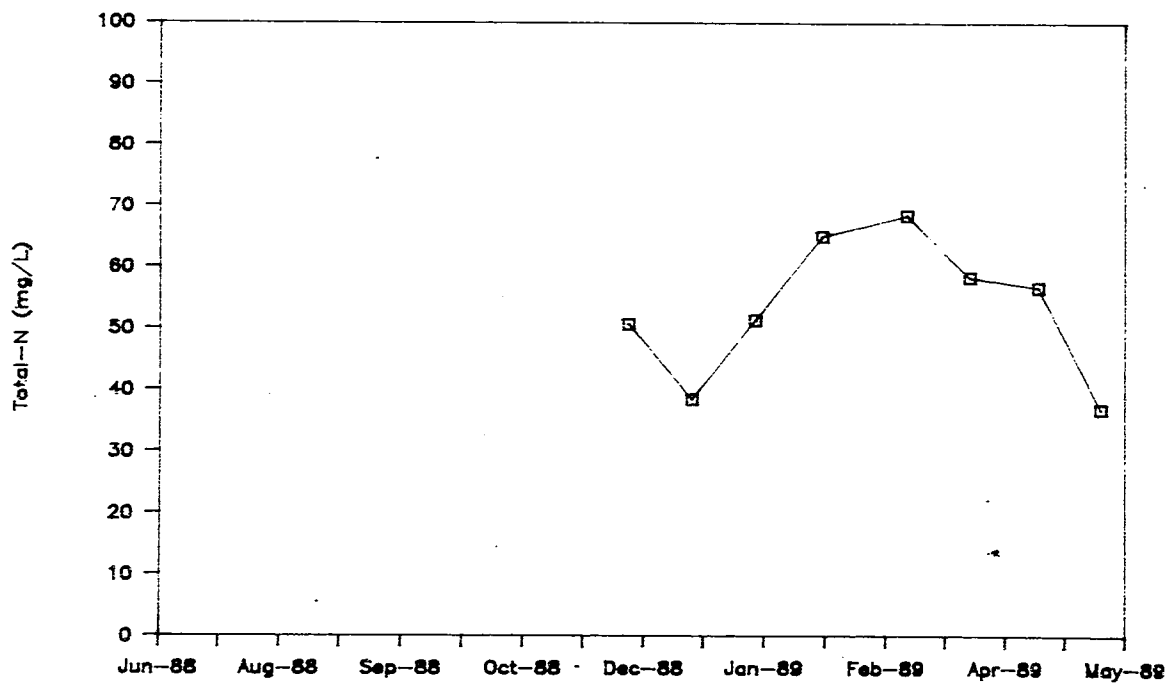
The total-N concentrations in rock tank effluent for Systems D and K from Foster Cove are shown in Figure 4. As can be seen, both systems exhibited variability in total-N concentrations over the course of the study, with average total-N concentrations during the study period for Systems D and K of 30.5 mg/L (S.E.=1.9 mg/L) and 53.3 mg/L (S.E.=4.0 mg/L), respectively. Greywater contributed approximately 30-40% of the total-N in the rock tank effluent. As with nitrification and denitrification, System K appeared to show seasonal affects on total-N concentrations. Even with the possibility of 5-40% more total-N removal in the soil absorption field, total-N concentrations leaving both Foster Cove systems would exceed the 10 mg/L Federal drinking water standard for  $\text{NO}_3^-$ -N. The total-N concentrations observed in rock tank effluent at Foster Cove are on the high end of observations from other studies. As a comparison, average total-N concentrations in rock tank effluent in Experiments 1 and 2 at U.R.I. were 23 mg/L (S.E.=1.4 mg/L) and 18 mg/L (S.E.=1.3 mg/L), respectively and 10.2-37.2 mg/L for 18 of the New Jersey systems. System K at Foster Cove had the highest total-N concentrations in rock tank effluent of any of the systems studied.

Figure 4. Total-nitrogen Concentrations (mg/L) in Rock Tank Effluent.

### SYSTEM D



### SYSTEM K



## CONCLUSIONS AND RECOMMENDATIONS

The results presented here suggest that RUCK on-site sewage disposal systems can provide varying degrees of removal of total-N from household wastewaters. System D and System K studied at Foster Cove in Charlestown, Rhode Island had average total-N removal rates of 54% and 29% before entering the soil, respectively, resulting in total-N concentrations in the final system effluent of 30.5 mg/L and 53.3 mg/L. Incomplete nitrification in the sand filters of both systems (average of 57-58%), incomplete denitrification in the rock tank of System K (average of 62%) and elevated greywater TKN concentrations in both systems were all factors which contributed to the relatively low rates of total-N removal observed.

The composition of the greywater which served as the carbon source for denitrification in the rock tanks appeared to be quite variable. Greywater analyzed from a number of systems in Rhode Island and New Jersey exhibited a wide range of TOC and TKN concentrations, with no clear relationship observed between TOC concentrations and % denitrification. Although  $C:NO_3^-$ -N ratios in effluent entering the rock tanks were assessed, there also did not appear to be any definitive relationships between these ratios and % denitrification. System K at Foster Cove was the only full-scale residential RUCK system studied which did not routinely show 100% denitrification. The incomplete denitrification in System K may have resulted from the composition of the greywater; the greywater in System K appeared to be composed of only kitchen and laundry wastewaters while the greywater in System D was composed of all non-toilet wastewater. In all instances greywater contributed TKN directly to the rock tank, indicating a disadvantage of using greywater as a carbon source for denitrification. Carbon sources such as methanol and ethanol do not add any additional TKN to the rock tank, although they have the disadvantage of not being generated on site.

Despite similar system design, a wide variability in performance was observed for the RUCK systems studied in New Jersey and Rhode Island. System D at Foster Cove had nitrification rates, denitrification rates and rock tank total-N concentrations within the range of values exhibited by the systems being studied elsewhere. System K had lower denitrification rates and higher rock tank effluent total-N concentrations than most other systems monitored, indicating that perhaps the performance of System K is somewhat atypical. Further testing is recommended to firmly establish the nitrogen removal capacity of RUCK systems in Rhode Island. Long term studies are also needed to assess the nitrification efficiency and clogging potential of the buried RUCK sand filters as they mature. New designs for the nitrification component of the system may be warranted since incomplete nitrification was observed routinely in all Rhode Island RUCK systems.

#### ACKNOWLEDGEMENTS

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# APPENDIX I

## DOCUMENTATION FOR LOTUS WORKSHEET

The following documentation describes variables and column locations for a Lotus 1-2-3 worksheet containing the data for the final project report for the study entitled "Field Evaluation of Nitrogen Removal Septic Systems For Coastal Communities".

Column	Variable Description
A	Sampling date
B	<div> Sample ID <div> <div>F</div> <div>C</div> <div>D</div> <div>S</div> <div>F</div> </div> <div> <div> </div> <div> </div> <div> </div> </div> <div> Foster Cove System D Sand Filter Effluent </div> </div> <div> Ex.: <div> F C D S T = System D, Blackwater septic tank effluent F C D S F = System D, Sand filter effluent F C D R T = System D, Rock tank effluent F C D G W = System D, Greywater septic tank effluent F C K S T = System K, Blackwater septic tank effluent F C K S F = System K, Sand filter effluent F C K R T = System K, Rock tank effluent F C K G W = Ssystem K, Greywater deptic tank effluent </div> </div>
C	Chloride concentrations, mg/L
D	Nitrate-nitrogen ( $\text{NO}_3^-$ -N) concentrations, mg/L
E	Nitrite-nitrogen ( $\text{NO}_2^{2-}$ -N) concentrations, mg/L
F	Total Kjeldahl nitrogen (TKN) concentrations, mg/L
G	Ammonium-nitrogen ( $\text{NH}_4^+$ -N) concentrations, mg/L
H	Total organic carbon (TOC) concentrations, mg/L
I	pH units
J	Alkalinity, mg/L $\text{CaCO}_3$
K	Temperature, °C
L	Total-nitrogen (TN), mg/L $\text{TN} = \text{TKN} + \text{NO}_3^- \text{-N} + \text{NO}_2^{2-} \text{-N}$
M	Nitrification in sand filters, %
N	Total-N (TN) removal in sand filters, %

Column	Variable Description
O	NO <sub>3</sub> <sup>-</sup> -N concentrations entering the rock tanks, based on flow ratios below
P	Denitrification in rock tanks, %
Q	Total-N (TN) entering each system through combined greywater and blackwater flows, based on flow ratios below
R	Total-N removal for system at rock tank outlet, % based on flow ratios below
S	Carbon (TOC) concentrations entering the rock tank, mg/L based on flow ratios below
T	TOC:NO <sub>3</sub> <sup>-</sup> -N ratios entering rock tanks, based on flow ratios below

Flow ratios used for the two systems were:  
 System D - 80% greywater:20% blackwater  
 System K - 60% greywater:40% blackwater