Nitrogen Removal Efficiencies of Three Alternative Septic System Technologies and a Conventional Septic System[a]

Joseph E. Costa[1], George Heufelder[2], Sean Foss[2], Newton P. Milham,[1,3] Brian Howes[4]
[1]Buzzards Bay Project National Estuary Program,
Massachusetts Office of Coastal Zone Management
2870 Cranberry Highway, East Wareham, MA 02538

[2]Barnstable County Department of Health and the Environment,
Superior Courthouse, Rt. 6A, Barnstable, MA 02630

[3]Present address Westport Water Resources, 672 Drift Rd., Westport, MA 02790

[4]School of Marine Science and Technology, University of Massachusetts Dartmouth,
706 Rodney French Blvd., New Bedford, MA 02744

Abstract

At a septic system testing center, conventional design onsite wastewater disposal ("Title 5") systems, were found to have a net nitrogen removal capability of 21-25% when data from the base of the Soil Absorption System (SAS) was considered, after accounting for an assumed precipitation recharge dilution of 10%. This reduction occurs principally in the soil absorption system, a component that is often overlooked in comparative studies. Nitrogen losses in the septic tank ranged from 1% to 3%. Successful proprietary nitrogen removal systems tested like the Waterloo Biofilter trickling filter and MicroFAST Model 0.5 systems had a net nitrogen removal capability of 60% and 55% respectively, thus discharging slightly more than half the nitrogen discharged by a conventional system. In these technologies, most nitrogen reduction occurred prior to discharge to the SAS.

The recirculating sand filter (RSF) designs tested removed approximately 41% of influent nitrogen, but we did not examine SAS losses, and overall system performance may be slightly better than this with a SAS installed. Without the SAS, the RSFs tested discharged 25% less nitrogen to groundwater than the Title 5 systems. Conventional septic systems with a Geoflow Wasteflow Drip Line system in the SAS removed 42% of influent nitrogen overall, showing that the performance of a SAS can be improved by injecting discharge near the topsoil, to allow nitrogen uptake by grass and other vegetation. This Drip Line design, combined with another septic tank technology could result in very high overall system nitrogen removal rates. One experimental design (ECO-RUCK) had a nitrogen removal ability less than a conventional system and was withdrawn after one year of testing.

Introduction

In 1999, the Buzzards Bay Project National Estuary Program, a unit of the Massachusetts Office of Coastal Zone Management, in partnership with the Barnstable County Department of Health and the Environment, UMass Dartmouth School of Marine Science and Technology, Massachusetts Environmental Trust, and the Massachusetts Department of Environmental Protection, constructed a facility to test and promote alternative and innovative onsite wastewater disposal systems in Massachusetts. This "Massachusetts Alternative Septic System Test Center" (MASSTC), located at the Massachusetts Military Reservation on Cape Cod, Massachusetts, has been testing three replicates of each participating innovative technology system and comparing their performance to three replicates of a conventional Massachusetts onsite wastewater disposal system. This conventional onsite wastewater disposal system, commonly referred to as a "Title 5" system after the state environmental codes defining its use, consists of a septic tank to clarify the effluent, and a soil absorption systems (SAS, sometimes also called a "leaching field") to provide a minimum level of treatment, principally for pathogen removal.

After nine to twelve months of testing, we compared (Millham et al., 2000) preliminary results of removal efficiencies of TSS, BOD, fecal coliforms, and nitrogen for three technologies (Waterloo Biofilter® trickling fil-

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ter, aeration with foam media., BioMicrobics MicroFAST® Residential Unit Model 0.5, and the ECO-RUCK by Innovative RUCK®) to the performance of a Title 5 system. In our report, an adjustment was made in the nitrogen removal results to account for dilution of the effluent by precipitation into the SAS. To account for this dilution, we used the difference in specific conductivity in the septic tank or technology effluent discharge (just prior to discharge into the SAS), and the specific conductivity of the leachate in the sump at the base of the SAS. In this report, technology of septic tank effluent was sampled in a distribution box or "D-box", and so labeled in the figures. SAS leachate is labeled "SAS base" in the figures.

With this conductivity data, dilution was estimated in that report using this equation:

adjusted nitrogen conc. = observed nitrogen conc. x (mean **D-Box** sp. cond.)/(mean **SAS base** sp. cond).

This approach led us to conclude that nitrogen removal by the SAS in a conventional Title 5 system was less than 10%. This finding contradicted other studies where higher rates of nitrogen removal were documented in a conventional system SAS (e.g. see review by EPA, 2002).

We have determined that the differences in specific conductivity that we observed and used in our earlier calculations, did not adequately account for dilution of the SAS leachate by rainwater because of changes in ionic concentrations or differing oxidative state of the effluent, which may have confounded this calculation. We believe these factors led to an overestimate of effluent dilution in the SAS in two of the technologies, which in turn, led to an underestimate of their nitrogen removal capabilities, particularly within the Title 5 SAS.

In this report, we use a refined estimate of the dilution of the effluent by precipitation collected in the SAS, which in turn is used to refine our earlier estimates of net discharge of nitrogen from each technology. These estimates are an improvement over those reported in Millham et al, 2000. We also present two years of data for the initial technologies, and include the first year performance of two additional technologies: the "Geoflow Drip Line with Rootguard" (henceforth simply "Geoflow"), and two variations of a non-proprietary recirculating sand filter (RSF) design.

Methods

Performance evaluations of onsite wastewater treatment technologies at the MASSTC are based on results from a standardized set of testing protocols on three identical replicates of each technology. The recirculating sand filter had only two replicates, and these replicates differed slightly in the recirculation of the effluent. Sewage intercepted from a sewer line that primarily serves U.S. Coast Guard personnel housing at the Massachusetts Military Reservation on upper Cape Cod, Massachusetts was directed to a central distribution channel at the Test Center (Fig. 1). Wastewater characteristics for nitrogen, total suspended solids, and biological oxygen demand at the Test Center are within the range considered typical of residential wastewater described by EPA, 2002. From the central distribution channel, sewage was pumped to triplicate units of each technology tested. Excess flow to the distribution channel was directed back to the sewer main.

Pumps conveying wastewater to the technologies' septic tanks were of the impeller type (Myers SRM4). Calibration of individual doses was by diversion of the flow into the septic tank inlet tee to a barrel calibrated to the dose volume (22 gal/ 83.3l). Each replicate was supplied with 330 gpd (1249 $l\ d^{-1}$) of wastewater. A programmable logic controller (PLC) operated the pumps. The number of on/off cycles and elapsed time were recorded down to the second by the PLC, along with a daily manual record. Sewage was supplied to each system in 15 equal doses primarily in the morning and evening, to simulate the pattern of wastewater discharge from an average household.

Effluent leaving the septic tank or technology-processing tank flowed by gravity to a conventional distribution box (D-box), where flow splitting and diversion was accomplished. The D-box has four outlet pipes (4in diameter; 10.2 cm), which were leveled during installation to provide equal flow through all four pipes. Usually, three of the four outlet pipes diverted flow to the test facility drain network; and the fourth conveyed flow to a SAS constructed to Massachusetts Title 5 design. Thus, of the 330 gallons per day flow to each replicate, 247.5 gallons (936.8 l) were diverted and 82.5 gallons (312.3 l) flowed to each SAS trench serving that technology. Because three replicates discharged to a single SAS, each SAS received 247.5 gallons per day from a technology.

Each technology replicate had one associated SAS (a single leaching trench within a larger SAS). The trenches were sized to achieve a dosage at the Title 5 design dosage limit of 0.74 gallons per ft^2 per day (32.2 $l\ m^{-2}\ d^{-1}$). The three replicate SAS trenches were underlined with an impermeable 30 mil PVC membrane, which collected both the leachate from the three SAS and precipitation infiltration. Thus, each lined technology SAS contained three leaching trenches (see Fig. 1). The liners under the SAS covered approximately 800 ft^2 (74.4 m^2). The combined SAS leachate and precipitation infiltrate collected in the liner sump and was pumped to the facility drain.

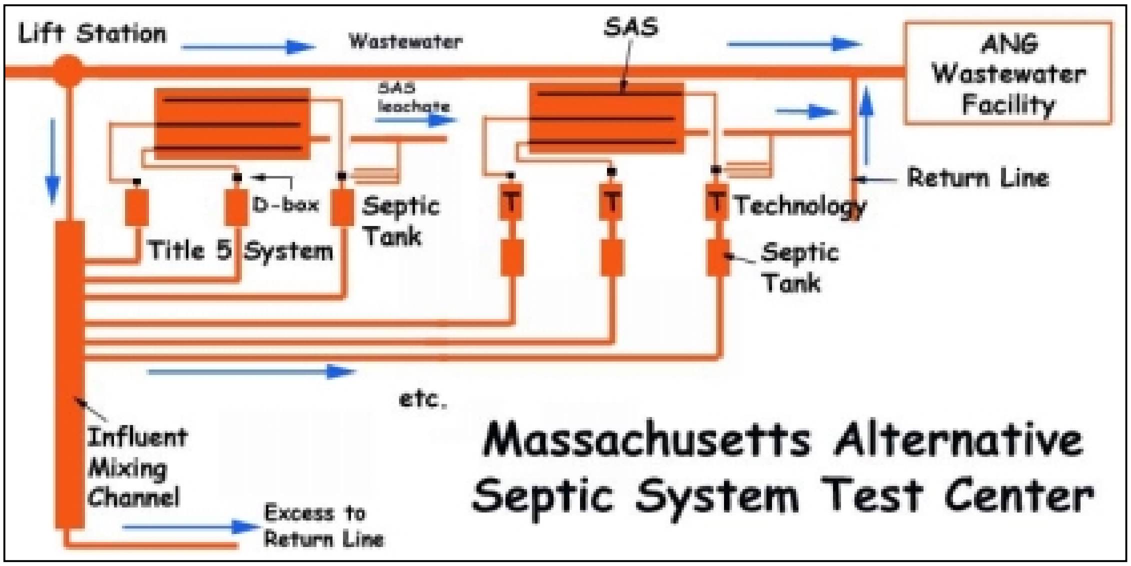

Figure 1. Conceptual design of the Massachusetts Alternative Septic System Test Center. Each technology and the conventional Title 5 systems were tested in triplicate, but discharged into a single SAS. Under each leaching trench in the SAS, pan lysimeters were installed, but the SAS base represented the mixed and combined effluent from the three replicates. Each D-box had four discharge pipes, only one of which flowed to the SAS. For simplicity, these waste lines are not shown.

Because the ECO-RUCK system was a SAS design, 100% of the flow went to the SAS. However, the flow was reduced to 220 gallons per day (833 l d^{-1}). Two ECO-RUCK replicates discharged to trenches in a SAS underlain with a liner covering 860 ft^2 SAS, and one replicate discharged in a trench installed in a 800 ft^2 lined area. Because of space limitations, and different objectives of testing, the RSF's did not have a leachfield and discharged directly to effluent lines leaving the Test Center.

Effluent from each technology was sampled bi-weekly using composite samplers set to collect 400-450 mls of sample at approximately 10 minutes following each of the 15 daily dosing periods. Temperature, pH, and specific conductivity were measured immediately following retrieval of the samples using Standard Methods (19th ed.) 2550, 423 and 205, respectively. Additional details of our sampling methodology and protocols can be found in Millham et al, 2000. For some technologies and components, sampling was less frequent. For example, few samples were collected from the ECO-RUCK D-Box because of performance problems with that technology, and particulate organic nitrogen (PON) was rarely collected from the base of SAS because it was so low or below detection limits.

At the Test Center, only two RSF technology replicates were installed. The RSFs consisted of a septic tank, sand filter and pump chamber. The sand filter area was 96 ft^2. One RSF sand filter was covered with plywood, one had a wood chips covering allowed rainwater infiltration. Both RSFs had an effluent return design to enhance denitrification. The plywood-covered filter had a splitter at the sand filter base to allow return of the effluent to the pump chamber, the other RSF had a float valve in the pump chamber.

To determine the removal efficiencies of various constituents by each technology, concurrent sampling was conducted principally within the Test Center's sewage distribution channel, immediately after the technologies themselves (or of septic tank effluent for SAS technologies), and within the SAS. The distribution channel was sampled at both ends (east and west), and data from that portion of the channel servicing each technology was used to determine nitrogen removal efficiencies. The Title 5 system was supplied with sewage from the west end of the sewage distribution channel, so technologies on the east end of the channel (MicroFAST, RSF, and ECO-RUCK), required comparisons of total nitrogen in both ends of the channel.

The technology treatment unit discharge was typically sampled in the distribution box (D-box) or comparable area, immediately before the discharge to the SAS. In the case of the Title 5 and ECO-RUCK system, the D-box follows a conventional septic tank. The technologies reported here all discharged to a SAS. The effluent samples were not taken at the Geoflow system D-boxes because they were adjacent to and considered identical in composition to the Title 5 D-box effluent.

For all technologies except the ECO-RUCK, pan lysimeters were placed one, two and five feet beneath each replicate SAS. The ECO-RUCK SAS was deeper than the rest of the SAS so that the locations of pan samplers were possible at only one to three feet. In addition, samples were collected at the base or "sump" of the SAS (5 ft), which was lined to collect all SAS leachate and prevent its discharge to groundwater. Impeller design pumps collected SAS leachate and discharged this treated wastewater to exit lines. These discharge lines had flow meters installed.

Not all pan collectors under each trench within the SAS were equally effective in capturing leachate, so we used the data from leachate at the base of the SAS as representative of overall nitrogen attenuation performance for that technology. Because the base of the SAS collects leachate from each of the three trenches for the three replicates, it represents a physical mixture of the three replicates. The exception to this design was the ECO-RUCK installation, which had two replicates discharging to one SAS while the third had its own SAS. For these reasons, most of the data presented in this report are for the SAS base, and not individual pan lysimeters.

In our region, recharge has been estimated to be about 50% of annual precipitation (LeBlanc et al., 1986; Cambareri and Eichner, 1998). For example, between March 2000 and March 2001, we received 0.98 m of rain (University of Massachusetts Wareham Cranberry Experiment Station data). Theoretical recharge of precipitation in our 74.4 m^2 SAS could average 25.8 gallons per day, or 10% of our SAS leachate dosage rate of 247.4 gallons per day. Of course, actual recharge rates vary with actual rainfall amounts, season, and vegetation types. In our study, we estimated dilution of effluent in the SAS by reviewing local rainfall data during the precise test period for each technology. We compared this theoretical recharge of rainfall to SAS pump records and flow meters, conductivity data, chlorides and bromide tracer data. These data do not all agree, and there is some uncertainty to precisely how much SAS effluent is diluted in our system by rainwater (paper in preparation). However, for this report, as a best approximation of all available information, we have adopted an interim annual average dilution rate of 10% within the SAS for the Title 5, MicroFAST, Geoflow, and Waterloo Biofilter systems. For one ECO-RUCK SAS, we adopted a 7% dilution rate, and 13% the other because of the higher effective dosage rates for the SAS and differing number of replicates in each SAS. The RSFs did not have a SAS, and the estimated 0.9% dilution from rain infiltration was ignored on the replicate with a wood chip covered sand filter.

Technology performance reported here differs somewhat from the previously reported results published by the Buzzards Bay Project in interim findings one-year performance fact sheets in 2001. These differences are the result of several possible factors including: two years of data were evaluated for some technologies, slightly different performance periods were evaluated for technologies or specific replicates, certain data may have been revised because of quality assurance evaluations, and in the case of the ECO-RUCK system, a different dilution factor was adopted for the second SAS. In this report, technologies were compared to data in the influent channel closest to where they received influent. This differs from past reports where data from both sides of the influent channel were averaged.

Results

Generally, mean total nitrogen concentrations at each end of the influent channel were within 0.5 mg l^{-1} of each other, and were not statistically significant (Student's T-test, two-tail, $P<0.05$), although the east end samples did appear slightly consistently higher in total nitrogen. For example, during the evaluation period for MicroFAST, the west end of the influent channel, which supplied the Title 5 system, had a total nitrogen concentration of 35.10 (n=45, S^2=3.53), whereas the east end, which was the area supplying the MicroFAST replicates, had a nitrogen concentration of 35.32 (n=48, S^2=3.55).

In Figures 2-6, we show the performance of five alternative design wastewater systems tested, compared to the performance of the Title 5 systems during the same period. Data shown is for the average of all samples taken for the three replicates during the testing periods shown in Table 1. In the graphs, NH4 stands for ammonia,

Table 1. Periods of evaluation for each technology and origin of effluent from the Distribution channel. The Title 5 systems were operational during the entire period.

Technology	Influent	Replicates	Evaluation	Period
Waterloo	West	Rep 1 & 2	7/7/1999	6/19/2001
		Rep 3	7/7/1999	11/28/2000
MicroFAST	East	Rep 1 & 2	6/9/1999	5/8/2001
		Rep 3	6/9/1999	4/24/2001
Geoflow	West	Reps 1-3	3/1/2000	3/1/2001
ECO-RUCK	East	Reps 1-3	9/1/1999	7/12/2000
RSF	East	Reps 1 & 2	3/1/2000	3/1/2001

NOx stands for the combined total of nitrate plus nitrite, DON stands for dissolved organic nitrogen, and PON stands for particulate organic nitrogen.

Total nitrogen at the top of each bar is the total the additive means of all the constituent forms of nitrogen. This method of calculation overcame occasional absence of concentration of a nitrogen constituent from an omitted sample, or where certain measurements were rarely performed because concentrations were typically low, or below detection limits (e.g. PON measurements in the SAS base were infrequent). In some cases the additive means sometimes differed a few percent from the mean total nitrogen values. However, the percent reductions in nitrogen were generally nearly identical whether the actual available total nitrogen concentrations or additive parameter mean values were used.

As shown in Fig. 2, the Waterloo Biofilter had a net nitrogen removal efficiency of 60%, as compared to 25% nitrogen removal efficiency for the Title 5 system during the same period. Thus, the Waterloo discharged about 54% of the nitrogen than a conventional system (a rainfall dilution adjusted concentrations 14.1 mg l^{-1} total nitrogen compared to 26.2 mg l^{-1} for the Title 5 system). The MicroFAST had a similar performance (Fig. 3). It had a net nitrogen removal efficiency of 55%, as compared to a 25% nitrogen removal efficiency for the Title 5 system during the same period. This technology's nitrogen discharge of 15.8 mg l^{-1} was 60% of the Title 5 discharge of 26.3 mg l^{-1}.

The RSF (Fig. 4) and Geoflow (Fig. 5) were less effective at removing nitrogen than the MicroFAST and Waterloo Biofilter systems. Both the RSF and Geoflow removed 41% and 42% respectively of the influent nitrogen, discharging about 22% and 25% respectively less nitrogen to groundwater than a conventional Title 5 system. However, in the case of the RSF, because no SAS was installed and sampled, we cannot fully quantify nitrogen removal from typical installations of this technology because it is likely some additional nitrogen removal occurs in the SAS like the other technologies. For the RSF, effluent leaving the technology was 21.2 mg l^{-1} total nitrogen at the D-Box as compared to 15.0 and 17.8 mg l^{-1} total N respectively leaving the Waterloo Biofilter and MicroFAST D-boxes. Although the two RSFs were of differing design, their mean total nitrogen discharges (20.5 mg l^{-1} for the wood chip covered sand filter replicate and 21.8 mg l^{-1} for the other) were not statistically different (Student's T-test, two-tail, $P<0.05$).

In the case of Geoflow, nitrogen removal by the SAS Drip Line system was an improvement over a conventional Title 5 SAS alone. The grass over the SAS in these systems was exceptionally lush and grew quickly, requiring more frequent mowing. Clearly, some of the effluent nitrogen is incorporated into this additional plant biomass. Grass clippings were usually removed by raking these plots after mowing. Some of the lost nitrogen may have also been removed through biomicrobial cycles in the topsoil.

In contrast to the other technologies, the ECO-RUCK performed poorly with respect to nitrogen removal (Fig. 6). Both the Title 5 systems and ECO-RUCK systems discharged comparable effluent from their D-boxes (the lower DON in the ECO-RUCK may be a reflection of the fact that only two DON measurements were taken in the SAS base of that technology), yet the ECO-RUCK had a net nitrogen removal efficiency of only 12%, as compared to a 21% nitrogen removal efficiency for the Title 5 system during the same period.

The annualized results summarized in Figs. 2-6 fail to capture some important differences among the systems. For example, the MicroFAST shows a very strong seasonal trend in nitrogen removal efficiencies, with

DIN concentrations typically between 13 and 19 mg l^{-1} in winter and between 7 –10 mg l^{-1} in summer (data not shown). It also performed better in the first year than the second. The Waterloo Biofilter shows a less pronounced seasonal trend with DIN between 11 and 16 mg l^{-1} in winter and 6 and 9 mg l^{-1} in summer (data not shown). The MicroFAST also often shows more variability in the fraction of effluent discharged to the SAS as ammonia. This latter effect is probably because the MicroFAST unit air blower discharge, which is sited within the second chamber of a septic tank, causes wide-ranging changes in the reductive state of the effluent in the tank. The seasonality of performance and variability of among technology replicates will be addressed in a subsequent report.

Despite differences among system performance and design, there were also some important similarities. For example, at the base of the SAS, all the systems discharged between 85%-95% of their nitrogen in the form of nitrates.

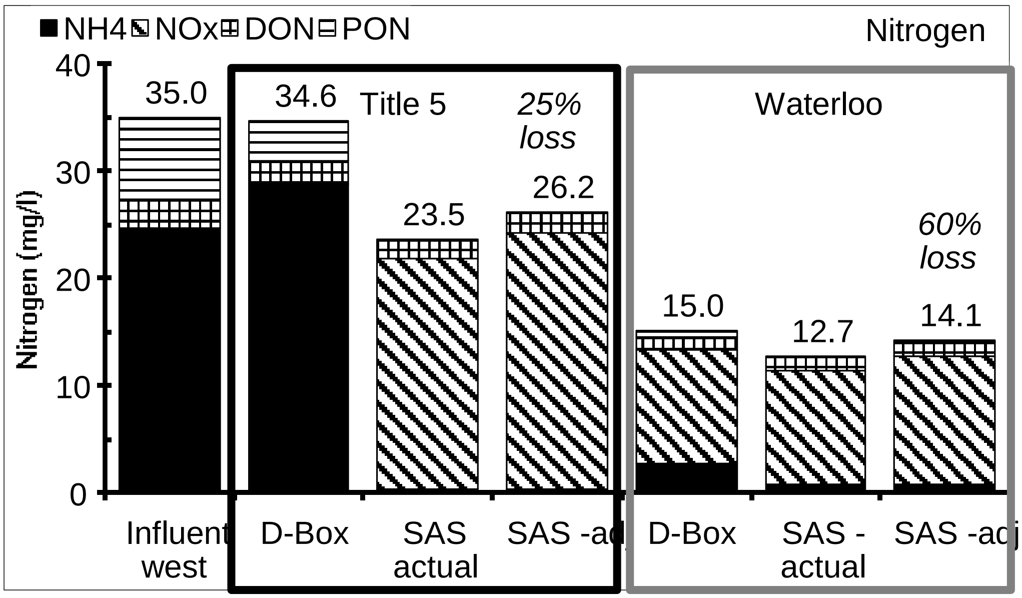

Figure 2. Observed nitrogen concentrations in the Waterloo Biofilter during the period 9/1/99 to 9/1/01 compared to influent and Title 5 performance during the same period.

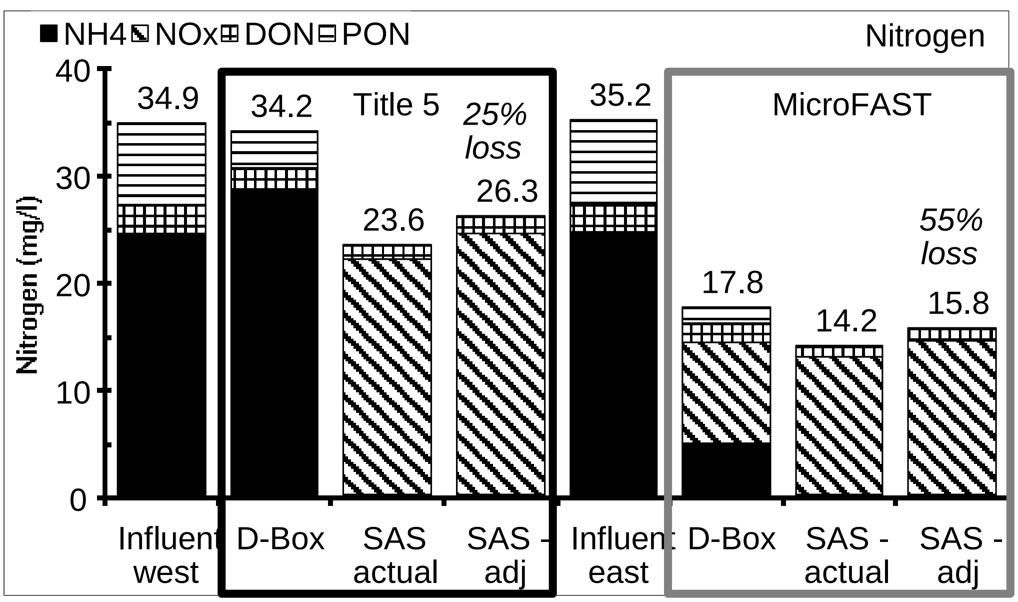

Figure 3. Observed nitrogen concentrations in the MicroFAST during the period 7/1/99 to 7/1/01 compared to influent and Title 5 performance during the same period.

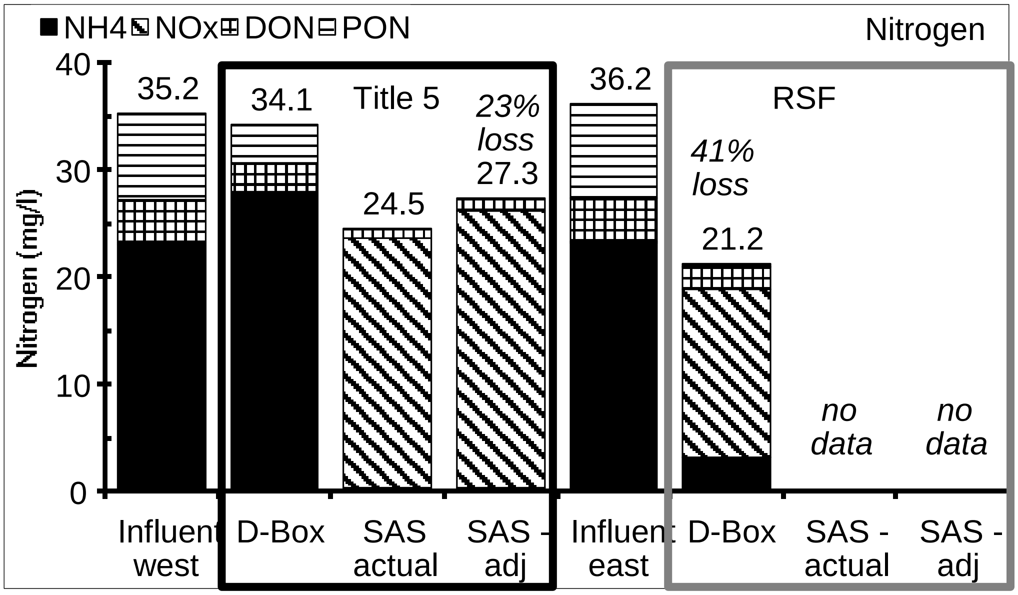

Figure 4. Observed nitrogen concentrations in the Recirculating Sand Filter (RSF) during the period 3/00 to 3/01 compared to influent and Title 5 performance during the same period.

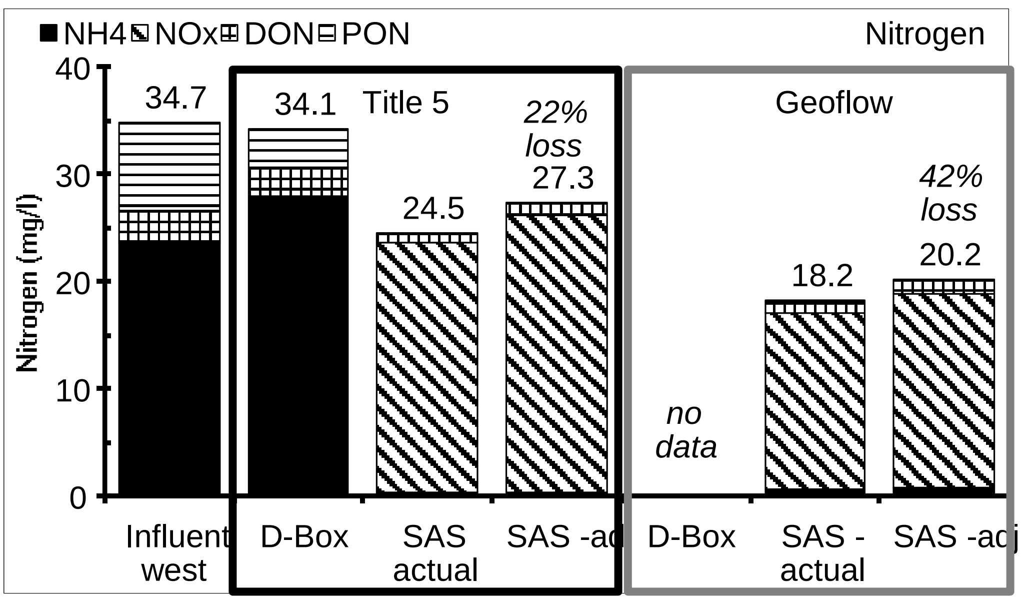

Figure 5. Observed nitrogen concentrations in the Geoflow during the period 3/1/00 to 2/1/02 compared to influent and Title 5 performance during the same period.

Discussion

In evaluating the nitrogen removal performance of wastewater disposal systems, nitrogen losses and dilution by precipitation in the SAS must be understood and documented. We observed a general agreement between metered SAS discharge flow, estimated effluent dosing rates to the SAS, bromide tracer data, and local rainfall data and assumed recharge rates, to allow us to conclude that precipitation dilutes effluent contaminants in these SAS between 6% and 12% on an average annual basis (not shown, in preparation). This dilution is less than what might be typically observed in residential systems because the SAS of each technology at the Test Center was operated at maximum Title 5 design flow rates. In some cases we observed some discrepancies between measures

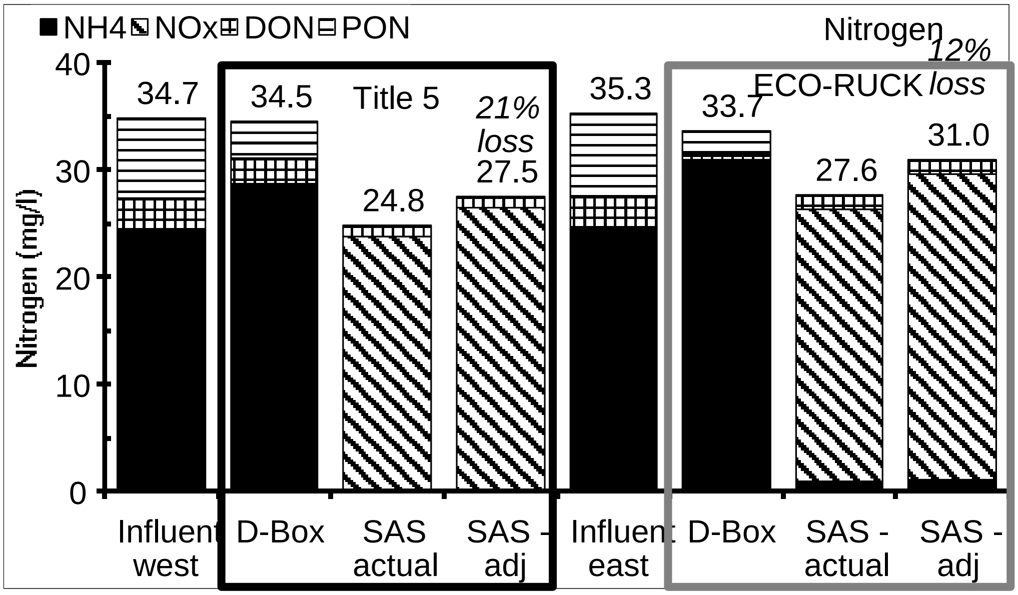

Figure 6. Observed nitrogen concentrations in the ECO-RUCK during the period 9/1/99 to 8/1/00 compared to influent and Title 5 performance during the same period.

of effluent flow and rainfall recharge, but these differences appear likely to be the result of metering pump mis-calibrations, greater than expected dosing at the D-Box, or some other factors.

Two technologies tested (Waterloo Biofilter and MicroFAST) discharge N principally as nitrate to the SAS and changes in conductivity in these technologies can be compared to estimated rainfall recharge dilution using other approaches. Both technologies showed a 15-16% reduction in conductivity in effluent passing through the SAS. This is somewhat higher than the adopted 10% dilution rate from rain recharge expected based on pump and flow meter data and rainfall amounts. This higher reduction in conductivity may be the result of changes of redox, nitrate and ammonia losses in the SAS, and solid-solution interactions within the SAS (Wilhelm et al., 1994a).

Despite uncertainties related to rainfall dilution in the SAS, on an interim basis, the MASSTC adopted an average annual dilution rate of 10% to evaluate relative nitrogen removal in the technologies, except the ECO-RUCK, because it had different dosing rates in the two SAS installed for that technology.

In a practical sense, we do not expect discrepancies in estimates of rainfall recharge to affect our estimates of nitrogen removal within the innovative technologies tested, because most of the achieved nitrogen removal occurs prior to discharge to the SAS. The presumed Title 5 performance is more sensitive to rainfall recharge estimates. Our current estimate of 21-25% nitrogen removal by a Title 5 was based upon an assumed 10% dilution of the effluent by rainwater recharge in the SAS and assumed effluent dosage of the three replicates in the SAS of 247.5 gallons per day. Based on the plausible extremes of potential rainwater recharge, actual effluent dilution factors could have ranged between 15% and 6%. For the Title 5 system, this suggests a nitrogen removal range of between 19% to 27%.

We recognize that such an average annualized approach does not account for likely higher dilution rates that occur during the spring when soils are saturated with water, and lower or negligible dilution rates that may occur during summer drought periods. Observed nitrogen concentrations could be adjusted by seasonal dilution factors to obtain a more precise estimate of SAS performance in nitrogen uptake, but bromide tracer and chloride data obtained to date at the MASSTC were not adequate for these purposes. Whatever dilution factors are employed in evaluating the SAS data, the correction factor is modest compared to the real performance differences between some technologies and conventional systems.

The poorly performing ECO-RUCK system provided insight as to the nitrogen removal capacity of a SAS in a standard Title 5 system. The ECO-RUCK was a new design concept (different from the standard RUCK already approved for use in Massachusetts), which was tested by the manufacturer at the MASSTC before its proposed introduction to the marketplace. Effluent from the ECO-RUCK septic tank discharged to an SAS consisting of a special medium fabric and plastic sheets, stone and sand, instead of soil typical in a Title 5 SAS. More-

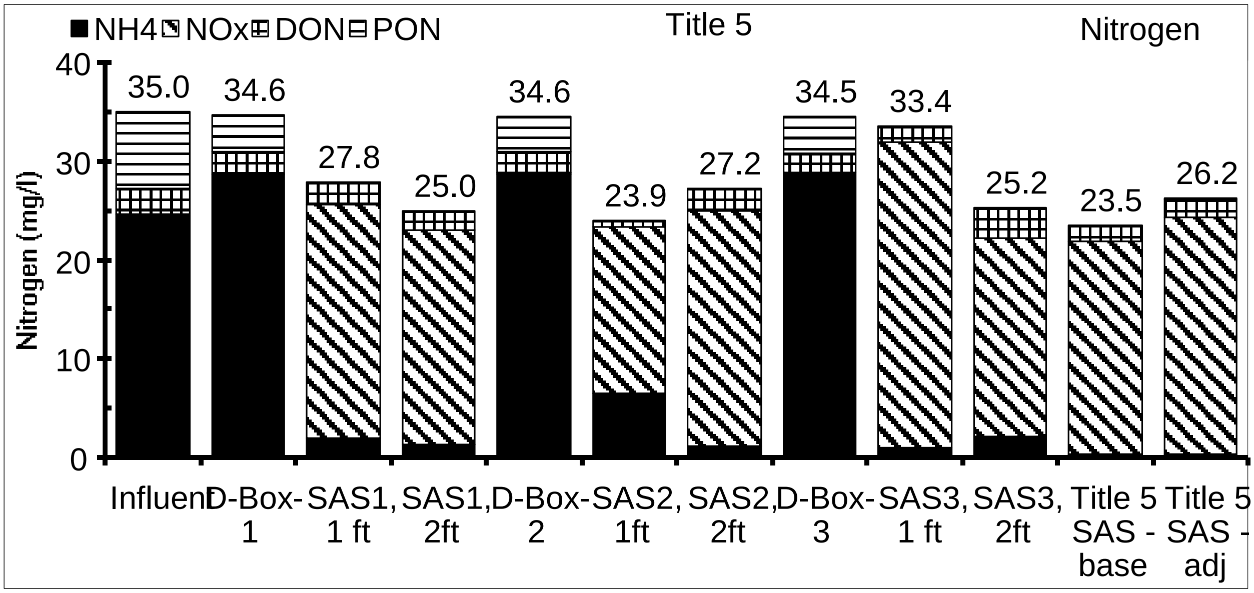

Figure 7. Observed nitrogen concentrations in the three replicates of the Title 5 system during the period 7/1/99 to 7/1/01. "SAS–adj " is effluent in base of the SAS, adjusted for presumed rain infiltration during the period.. No similar adjustment was made for the lysimeter data.

over, 25% of the effluent from the tank discharged to the base of the SAS in an attempt to create an alternating aerobic-anaerobic layer. This novel SAS did not perform as expected. Instead, the design enabled effluent to more quickly reach the base of the SAS, with less treatment and higher nitrogen concentrations than occurred in the Title 5 system.

The higher nitrogen concentrations discharged by the ECO-RUCK SAS support the presumption that a standard Title 5 system SAS does remove some nitrogen from wastewater effluent. In a standard Title 5 SAS, when anaerobic effluent with a high BOD load is discharged directly to a conventional SAS, a biomicrobial "mat" forms in an anaerobic-aerobic boundary within the first 30 cm under the trenches. It is in this zone that nitrification occurs, as well as ammonia binding to soils. It is also believed that some denitrification occurs in microenvironments in this zone.

This process contrasts sharply with most innovative nitrogen removal technologies. Typically, these systems remove nitrogen by first oxidizing ammonium in the septic tank effluent, and subsequently diverting the resulting nitrified liquor to an anoxic area, such as a primary chamber or a septic tank where sufficient carbon (BOD) is available. In this anoxic, carbon-rich environment, microbial conversion of nitrate to nitrogen gas (i.e., denitrification) occurs. The resulting highly treated, typically aerobic effluent, is then discharged to a SAS. In these types of technologies, the "microbial mat" observed in conventional systems may not form. It is precisely for these reasons that innovative technologies are often allowed to have smaller SAS or higher dosage rates because the absence of the bio-mat makes hydraulic failures less likely.

These differences in the biochemical environments within the SAS explain why only a small (3-6%) nitrogen reduction occurs in the SAS for the Waterloo Biofilter and MicroFAST, whereas a large (20%-24%) reduction occurred in the SAS of a Title 5 system. This finding of moderate nitrogen removal in a conventional wastewater SAS agrees with other studies where typically 10% to 40% nitrogen loss has been observed (e.g. Wilhelm et al., 1994b, review in EPA 2002).

In contrast to the SAS, little nitrogen loss occurred in the septic tank. Some studies like Andreoli et al. (1979) concluded that as much as 20% of total nitrogen discharged from a home is attenuated in a septic tank as accumulated septage sludge, with possible denitrification or volatilization. In our study, we have found this loss to be only between 1% and 3% in the Title 5 septic tanks, depending on the period of study. Our observed loss might be lower than some residential systems because of the relatively high hydraulic loading rates for septic tanks at the MASSTC.

In this study, the conventional Title 5 wastewater systems have a net nitrogen removal efficiency of 21-25%. We do not believe that ammonia binding by sediments contributes to these documented losses at the MASSTC because the binding ability of soils is likely exhausted during the three-month start-up period not included in the analysis.

We believe that the SAS base data is a reasonable integration of SAS performance as compared to individual pan lysimeters in the SAS. Results from these pan lysimeters tends to be variable (Fig. 7) because flow in a SAS is very heterogeneous and depends on the precise location of leaching pipe drainage holes, drainage pipe elevations, flow pathways altered by the pan lysimeters, and other factors. This pan lysimeter data contrasts sharply with the consistent data observed from the septic tanks (measured at the D-boxes). Because of the variability in the pan lysimeter data, we believe the SAS base is a good reflection of integrated SAS contributions to groundwater where the base of the SAS is near groundwater. The pan lysimeter data is being used to evaluate technology performance where less than a four-foot separation to groundwater is sought.

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Other information on this initiative can be found at www.buzzardsbay.org. The views or opinions expressed are not necessarily those of the Commonwealth of Massachusetts, the US EPA, or any of the funding organizations and agencies. The wastewater disposal system performance evaluations included in this report are for the specific designs tested. Modifications to system designs from those tested, or installation under other soil or climate conditions may result in different system performance.

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