GREYWATER CHARACTERIZATION AND TREATMENT EFFICIENCY

Final Report

for

The Massachusetts Department of Environmental Protection

Bureau of Resource Protection

By

Peter L.M. Veneman and Bonnie Stewart

Department of Plant and Soil Sciences

University of Massachusetts

December 2002

Summary

The objective of this study was to quantify the variability and characteristics of greywater sampled at five different commercial locations in Massachusetts. BOD_5 in greywater sampled just prior to discharge to the subsoil disposal facility averaged 128.9 mg/L with a range of 22.1-358.8 mg/L, TSS ranged from 8-200 mg/L with a mean of 53.0 mg/L, and TKN had a mean of 11.9 mg/L and a range of 3.1-32.7 mg/L. Nitrate values ranged between <0.8-17.5 mg/L with a mean of 1.5 mg/L. Orthophosphate content was generally below the detection limit of 0.5 mg/L with a highest measured value of 3.6 mg/L. pH values averaged 7.0, with a range of 5.3 to 10.8. Total coliform counts generally were high and exceeded our dilution ranges. Fecal coliforms ranged from 0 to values of 500 to 10,000 cu/100 mL. *E. Coli* was not detected in any of the samples.

A column study was run concurrently with the characterization study to assess the effect of soil depth and loading rate on treatment efficiency. Data showed a considerable variation both within and between different sites. Passing raw greywater through the columns resulted in a reduction of BOD_5 by a factor of 15 to 25 to 7.1 mg/L in Title 5 sand and 3.8 mg/L in sandy loam-textured Bw horizon material of a Montauk series, a typical southern New England soil. TSS values were reduced seven-fold to values of 5.0 mg/L for the sand and 6.0 mg/L for the sandy loam, respectively. TKN and orthophosphate values were generally close to detection limits (2.0 and 0.5 mg/L, respectively) in the column effluent, indicating virtually complete removal by the soil. Nitrate values were much higher in the column effluent than in the raw greywater with mean values of 9.9 for the sand and 12.9 mg/L for the sandy loam. This indicates that a significant amount of nitrification occurred. Total coliforms were present in significant amounts in the column effluents which was not surprising considering that these microbes occur in large quantities in the soil. At no time were any fecal coliforms, including E. Coli detected in the column effluents. This indicates a high efficiency of the soil in removing pathogens.

At the end of the column study, the greywater application rates were doubled. BOD_5 levels remained low with a mean of 5.2 mg/L. Mean TSS values averaged 6.0 mg/L. TKN and orthophosphates were always less than their respective detection limits of 2.0 mg/L and 0.5 mg/L. Nitrate concentrations ranged from 6.2 for the Title 5 sand to 5.7 mg/L for the Montauk soil. The data indicated that the effect of different loading rates was statistically not significant, but that soil depth was. This seems to point to the fact that increasing the loading rates does not appear to have an adverse effect on treatment efficiency, but that decreasing soil depth does.

Table of Contents

Background

One-third of the population in the U.S. uses on-site facilities to treat and dispose of domestic and commercial wastewater. While conventional, gravity-fed septic systems make up the bulk of these treatment systems, the last 2 decades there has been a renewed interest in alternative technologies that may overcome some of the site or environmental limitations typically associated with conventional septic systems. In a typical U.S. household each person on average uses between 50 and 60 gallons of water per day. Regulations that require low-flush toilets and flow restrictors on showers and faucets already resulted in significantly lower use of water. Other technologies, including composting and incinerating toilets, provide treatment of toilet and kitchen wastes (referred to as blackwater) separate from the wastewater from bathroom sinks, showers, and laundry (referred to as greywater). Most states have taken a conservative attitude towards the disposal of greywater and require generally the same design standards for greywater as for regular wastewater.

Conceptually, greywater should have much lower concentrations of various potential pollutants than blackwater, or conventional domestic or commercial wastewaters. Unfortunately, there is a paucity of reliable data about the true composition of greywater applicable to the Northeast. It was the aim of this study to provide typical background values of constituents in greywater derived from commercial sources.

This study, funded through the Bureau of Resource Protection of the Massachusetts Department of Environmental Protection, was initiated on March 1, 2001 and targeted monthly collection of five commercial greywater systems located throughout Massachusetts. The samples were analyzed for a variety of parameters including biochemical oxygen demand (BOD_5), total suspended solids (TSS), total Kjeldahl nitrogen (TKN), nitrate, orthophosphate, pH, coliforms (total and fecal), and *E. Coli*. The characterization study lasted one year and was terminated in June 2002. In addition to the characterization program we simultaneously carried out a column study using 15-cm diameter acrylic tubing filled with various heights of soil material. We included two different soil materials in our study, one a sand meeting Title 5 standards (Commonwealth of Massachusetts, 1995), the other a sandy loam-textured soil typical of Massachusetts subsoils. This report summarizes the results of this study. Supplementary data, including an extensive greywater literature review and the raw data generated from this project, may be obtained from a M.S. thesis based on this study (Stewart, 2003). In this report we present and discuss the characterization data first, followed by a description and discussion of our column study observations.

Specific objectives of this study were to:

- characterize greywater generated from commercial sources over a one-year period by measuring selected wastewater constituents, and
- evaluate, through a soil column study, the potential effect of different soil depths, loading rates, and differences in soil type on treatment efficiency.

Materials and Methods -Greywater Characterization Study

Sampling Site Selection
The study design originally called for sampling of 10 greywater systems. Sites sampled for the constituent characterization study were proposed by either Bill Wall of Clivus New England or David DelPorto of Sustainable Strategies and Affiliates. Sampling sites were selected and approved by DEP based on accessibility and whether or not the facility was a year-round operation. Unfortunately, we were only able to obtain permission to sample 5 sites. The remaining, large-scale commercial greywater systems in Massachusetts are either already monitored by the Lawrence Experiment Station, are inaccessible, or are seasonal in use. We consulted with Bill Wall and David DelPorto about the possibility of monitoring private greywater systems. None of the private system owners was willing to permit monthly sampling. Detailed descriptions of the DEP approved sampling sites are provided below. Sites were sampled on a monthly basis:

Lancaster Tourist Information Center (Mass. Highway). This site is located on Rt. 2 (west) in Lancaster, MA. Greywater is generated from 6 lavatory sinks, 1 janitorial sink, 3 floor drains, and 2 drinking fountains. Greywater from the system is directed to a pump chamber located in the basement. The effluent trickles into one side of the pump chamber and passes through three screen filters to the opposite side where it is pumped to the soil leaching facility at various intervals. Total volume of the pump chamber is 116 gallons. The average daily flow through the system is about 100 gallons. The pump cycles when about half of the chamber is filled with greywater resulting in a retention time of approximately 24 hours. Greywater quality at this location was extremely variable from month to month. Some microbial growth was observed on the filter screens and on the bottom of the collection tank.

This site also provided the greywater for our column studies. About 40 gallons of greywater were collected two times a week. Samples were taken from that section of the pumping chamber from which effluent is pumped directly to the leaching facility.

Walden Pond (DEM). This site was located at 915 Walden Street in Concord, MA. This site was accessible throughout the seasons. Greywater was collected from a pumping chamber similar to the one at the Lancaster Visitors Center. The chamber was located in the basement of the public lavatories which were located in a separate facility behind the main building. Greywater was generated from 4 lavatory sinks, 1 janitorial sink and 2 floor drains. This site utilizes a filter before discharge of the greywater into the pumping chamber. This pre-filter is composed of a nylon stretch filter supported by a plastic grate, which helps to create a biomat. After the greywater passes through the stretch filter, it passes through 3-4 inches of coal slag, and then through a biological oxidation medium called Actfil®. This material has a large surface area, which is meant to enhance biological growth. Greywater quality at this site was fairly consistent, which was likely due to the extensive filter system prior to discharge to the pump chamber. The pump chamber supported some biological growth on the filter screens and on the bottom of the tank. Samples were taken from the pumping chamber prior to discharge of the greywater to the soil leaching facility.

Minuteman National Park Visitor Center (U.S. Department of the Interior). This facility was located on Rt. 2A (Massachusetts Avenue) in Lexington, MA. Installation of the greywater system at this site had been completed just prior to the initiation of this study. The greywater at this site came from 3 lavatory sinks and 1 floor drain. There was no filter system or pumping chamber at this site as the greywater was combined with effluent from a urinal and discharged into a standard septic system. A spigot was installed in the cast iron pipe just prior where the different waste streams joined. The spigot was installed further into the cast iron pipe then the wall thickness of the pipe itself, resulting in the formation of a small lip where suspended solids tended to collect. Sampling at this site was very seasonal with hardly any traffic in the winter. In fact, there was only one date where all environmental variables could be tested. Park personnel generally opened the spigot prior to our arrival to ensure that sufficient greywater could be sampled. This effluent drained directly from the spigot into a 1-gallon polyethylene container.

Salisbury Beach State Reservation (DEM). This site was located on Interstate 495 in Salisbury, MA. Greywater was generated from 6 lavatory sinks, 1 janitorial sink, 3 floor drains, and 2 drinking fountains. The greywater drains to a 2000-gallon underground septic tank. To allow sampling of the greywater prior to reaching the septic tank, a spigot was installed in a cast iron pipe as was done at the Minuteman National Park Visitor Center. Similar to Minuteman, a lip inside the pipe was formed where particulate matter tended to build up which may have added suspended solids to the collected greywater sample.

Wellfleet Bay Sanctuary (Massachusetts Audubon Society). The center is located on West Road in South Wellfleet, MA. Greywater is generated from 4 lavatory sinks, 1 janitorial sink, 1 office sink, 1 wet laboratory, 1 drinking fountain, and 3 floor drains. The greywater passes through a filtertank located in the basement and is recycled through an indoor planter bed. Initially the greywater drained through a slag filter but about one year prior to this study this filter was replaced with a basket type filter containing Actfill® as a biological oxidation medium. Upon passing through this filter the greywater drains into a collection tank from where it is recycled to the planter bed. Along with some biological growth at the bottom, the collection tank supported the growth of unidentified larvae. Samples were taken from the collection tank just after the screen filter and prior to discharge to the flower beds.

Analytical Procedures

Greywater samples for the characterization study were collected on a monthly basis starting late June 2001 and terminating in June 2002. Three-gallon samples were collected from each site in acid rinsed, polyethylene containers. Samples were labeled using waterproof markers and noted in hard-cover, bound field books. Samples were transported to the laboratory on ice in insulated containers. Once in the laboratory, a 300-mL aliquot of each sample was acidified to a pH <2 with concentrated H_2SO_4 and kept at 4°C until further analysis for total nitrogen. Another sample portion was analyzed immediately for total and fecal coliforms, as well pH. If the remainder of the sample could not be analyzed immediately, the samples were kept at 4°C until further analysis for BOD, TSS, nitrate, and orthophosphate could be conducted. Where ever possible, we used EPA approved standard methods but due to the high sample volume, some EPA accepted test kits for wastewater manufactured by HACH Co. were employed. Details of each analytical procedure are provided in Stewart (2003). Quality control standards, including blanks and spiked samples, were used as appropriate.

TKN was measured in two steps. First samples were digested using a modified Kjeldahl digestion method (Benton, 1991), and than colorimetrically measured by the Nessler Method using EPA-accepted HACH method 8038.

Nitrate was determined by Standard Method 4500-NO_3 D (American Public Health Association, 1992) using an Orion 93-7 ion selective electrode. We used HACH Nitrate Interference Suppressor solution to counteract sample interference experienced initially.

Orthophosphate was measured using the ascorbic acid method following EPA-accepted HACH method 8048 (HACH, 1992).

Total Suspended Solids (TSS) were determined using Standard Method 2540 D (American Public Health Association, 1992).

Biochemical Oxygen Demand (BOD_5) was measured using Standard Method 5210 B (American Public Health Association, 1992). This method employs determination of dissolved oxygen before and after a 5-day incubation period.

Total and fecal coliform tests were performed using Standard Method 9222 B and 9222 D, respectively (American Public Health Association, 1992).

pH was determined with a Fisher Model 805 MP pH/Eh meter using standard calibration solutions.

Results and Discussion Greywater Characterization Study

All raw data generated through this project are presented in a M.S. thesis by Stewart (2003). Figure 1 show the fluctuation of the Biochemical Oxygen Demand over the entire monitoring period. Mean BOD_5 for Lancaster was 102.0 mg/L (range: 54.9-188.3 mg/L), Walden Pond: 131.6 mg/L (range: 58.3-305 mg/L), Wellfleet: 142.7 mg/L (range: 36.8-286.1 mg/L), Minuteman: 22.1 mg/L (only 1 observation), and Salisbury: 168.7 mg/L (range: 48.8-358.8 mg/L). Average BOD_5 over the entire period for all sampling stations was 128.9 mg/L (range: 22.1-358.8 mg/L). There was generally insufficient sample volume at Minuteman National Park, due to a lack of park visitors resulting in only one valid sample taken on 10/30/01. The highway stop at Salisbury was not equipped with a sampling valve until late November 2001. We sampled that site since December 2001. Although we are working with a limited data set, it appears that BOD_5 values increased during the winter and decreased again during the spring and summer (Fig. 1). Use of all of these facilities is weather dependent, with less visitors during colder months. There apparently is less dilution during the winter months resulting in higher BOD_5 values. We were unable to obtain appropriate water use figures from any of the facilities to evaluate the correctness of this argument. Typical BOD_5 values for greywater as reported in the literature range from 33-290 mg/L, while values for untreated domestic wastewater range from 100-400 mg/L (Siegrist, 1977).

Temporal fluctuations in total suspended solids (TSS) are presented in Figure 2. Mean TSS values in Lancaster were: 38 mg/L (range: 10-200 mg/L), at Walden Pond: 26 mg/L (10-50 mg/L), at Wellfleet: 68 mg/L (range: 20-200 mg/L), Minuteman: 80 mg/L (40-200 mg/L, 2 samples), and at Salisbury: 95 mg/L (range: 60-180 mg/L). Mean TSS value of all sites over the entire sampling period was: 53 mg/L (range: 8-200 mg/L). Both Wellfleet and Salisbury showed relatively high TSS values over the winter period which again may be due to a seasonal dilution factor. Typical greywater TSS values as reported in the literature range from 21-250 mg/L, while typical TSS values for untreated municipal wastewater in the U.S. range from 100-360 mg/L (Siegrist, 1977).

Total Kjeldahl nitrogen (TKN) values are presented in Figure 3. Means over the period of measurement were Lancaster: 8.1 mg/L (range: 3.1-17.7 mg/L), Walden Pond: 18.1 mg/L (range: 7.8-32.7 mg/L), Wellfleet: 9.7 mg/L (range: 3.2-19.7 mg/L), Minuteman 5.4 mg/L (1 observation), and Salisbury: 13.2 mg/L (3.5-31.6). The average TKN of all sites over the entire sampling period was 11.9 mg/L (range: 3.1-32.7 mg/L). Both Walden Pond and Salisbury showed much higher values than the mean. The TKN procedure does not account for nitrogen in the form of nitrite or nitrate, but because nitrate levels are low this effect was probably not significant. Typical TKN values for greywater range from 1-40 mg/L, whereas values for untreated domestic wastewater range from 16-75 mg/L (Siegrist, 1977).

At the Lancaster site nitrate values averaged 2.0 mg/L (range: <1.0-14.0 mg/L), Walden Pond: 1.2 mg/L (range: <1.0-7.7 mg/L), Wellfleet: 1.7 mg/L (range: <1.0-17.5 mg/L), Minuteman: <1 mg/L (1 measurement), and Salisbury: 1.0 mg/L (range: <1-1.8 mg/L). Average nitrate concentration for all sites was 1.5 mg/L (range: <1.0-17.5 mg/L). Fluctuations in nitrate content over the entire monitoring period are presented in Figure 4. Both Lancaster and Wellfleet exceeded the mean nitrate levels. At Lancaster this was caused by two sampling days with high nitrate values (10.3 and 11.5 mg/L, respectively), whereas one date at Wellfleet displayed an outlying value (17.5 mg/L). If these values are not considered in the mean, than all samples have nitrate concentrations at or below the detection limit of 1.0 mg/L. National average nitrate values for greywater range from 0-5.5 mg/L.

TKN/NO_3 ratios varied considerably with values for Lancaster of 4.1, Walden Pond: 15.1, Wellfleet: 5.7, and Salisbury: 13.2, respectively. Minuteman National Park had too few sampling dates. The data seem to indicate that a substantial portion of the nitrogen component of greywater is in the ammonium form. Walden Pond shows a gradual increase in BOD_5 over the sampling period. TSS values remained flat over that sampling period, indicating that dissolved organic compounds perhaps account for the increase in BOD_5.

Mean orthophosphate concentration for Lancaster was 0.6 mg/L (range: <0.5-2.3 mg/L),Walden Pond: 1.1 mg/L (range: <0.5-3.7 mg/L), Wellfleet: 1.0 mg/L (range: <0.5-3.6 mg/L), Minuteman: <0.5 mg/L (range: <0.5-0.8 mg/L) and Salisbury: 1.1 (range: <0.5-3.6 mg/L). Orthophosphate concentrations throughout the monitoring period are depicted in Figure 5. Total P greywater values reported in the literature range from 0.1-42 mg/L, whereas orthophosphate values for domestic wastewater range from 3-10 mg/L.

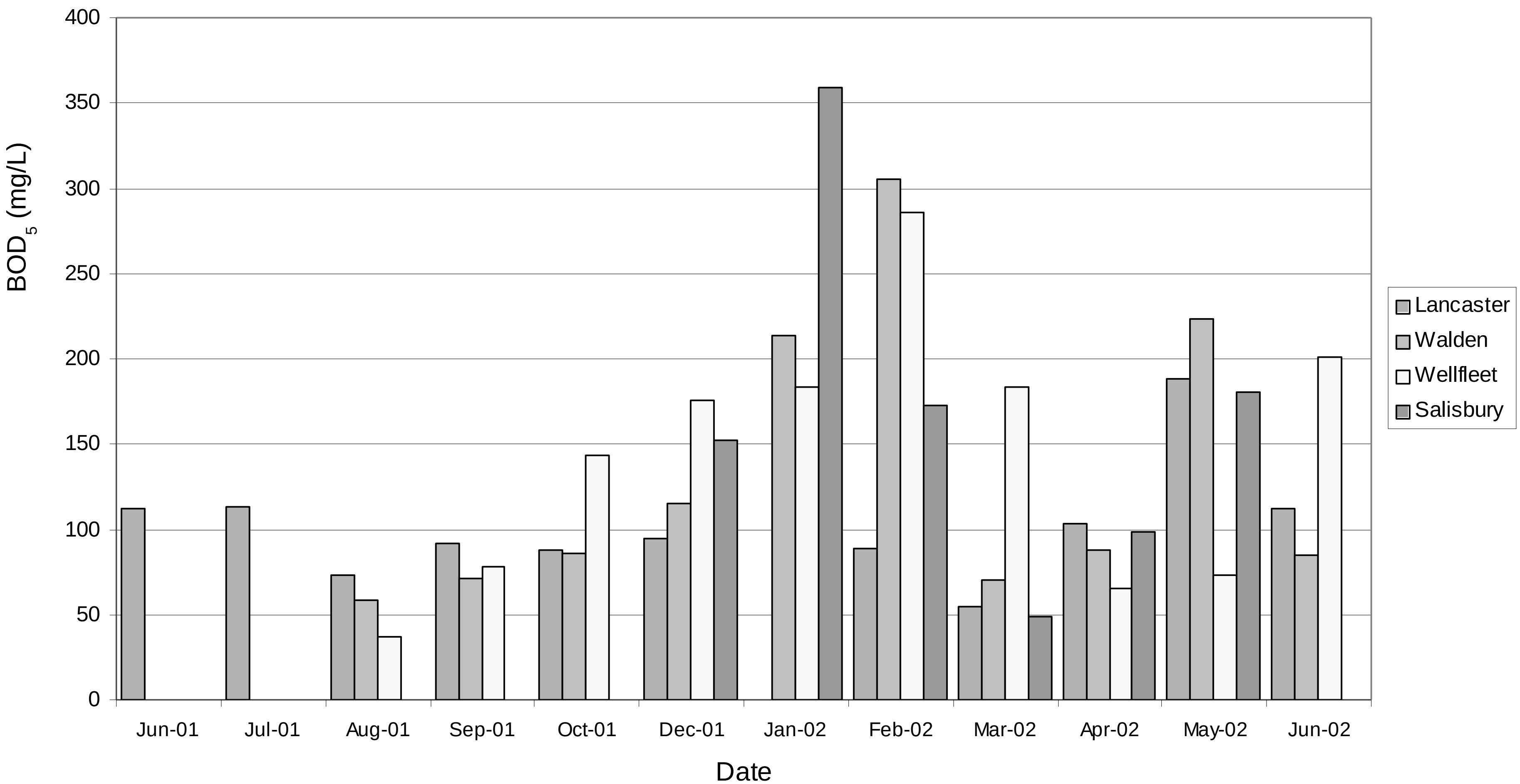


Figure 1. Biochemical oxygen demand (BOD_5) of greywater samples collected monthly state-wide.

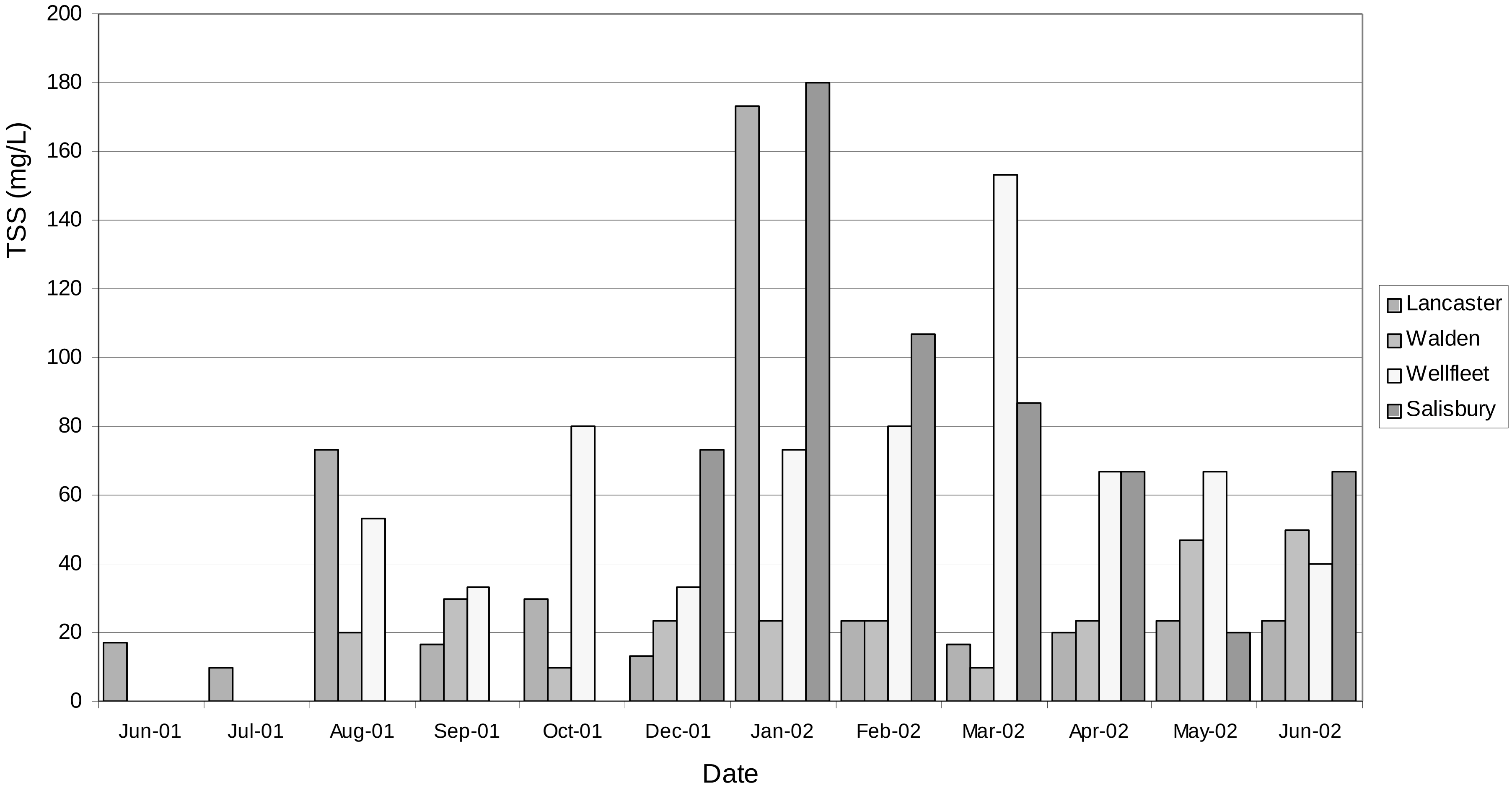


Figure 2. Total suspended solids (TSS) content of greywater samples collected monthly state-wide.

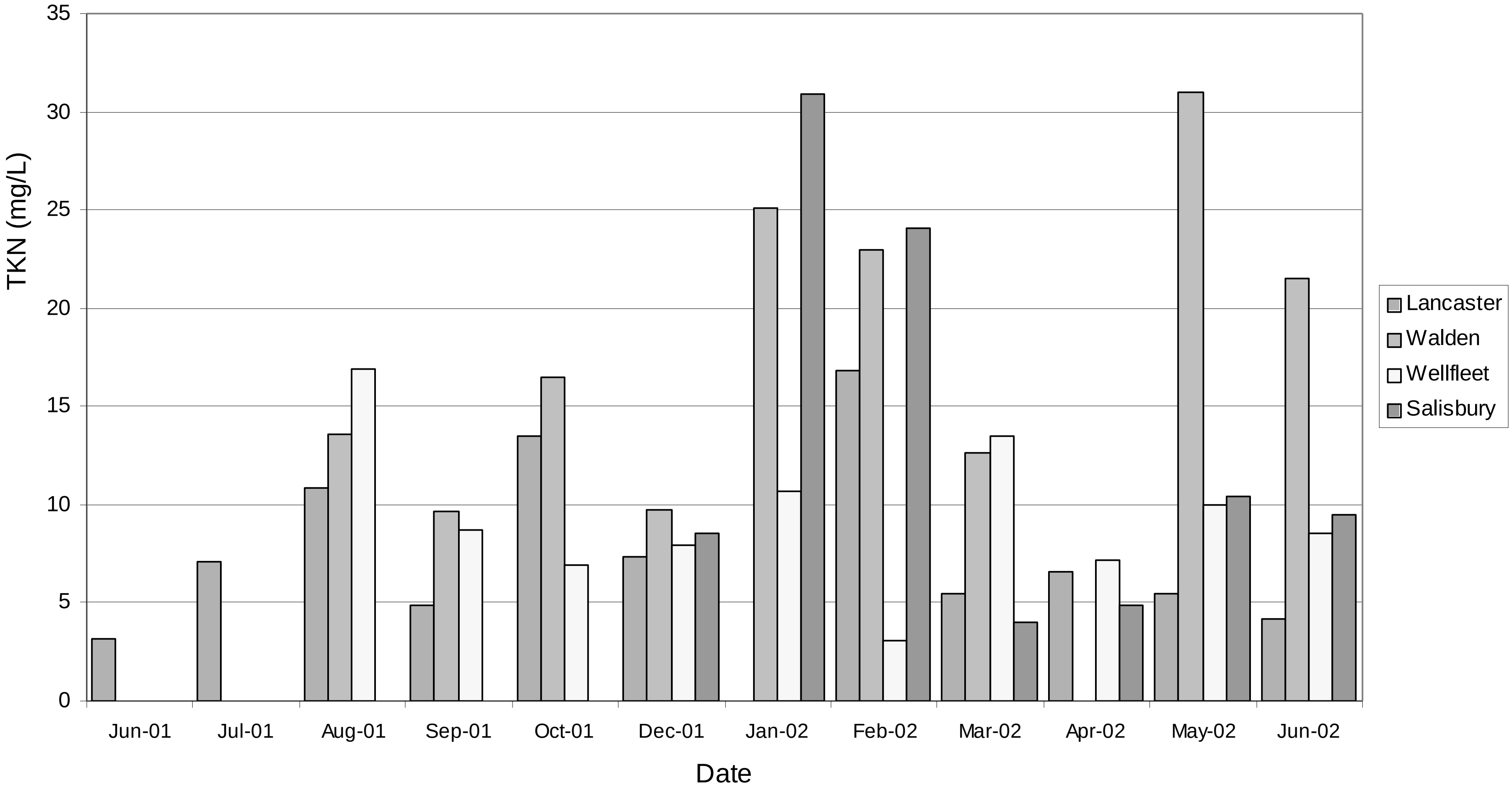


Figure 3. Total Kjeldahl nitrogen (TKN) content in greywater samples collected monthly state-wide.

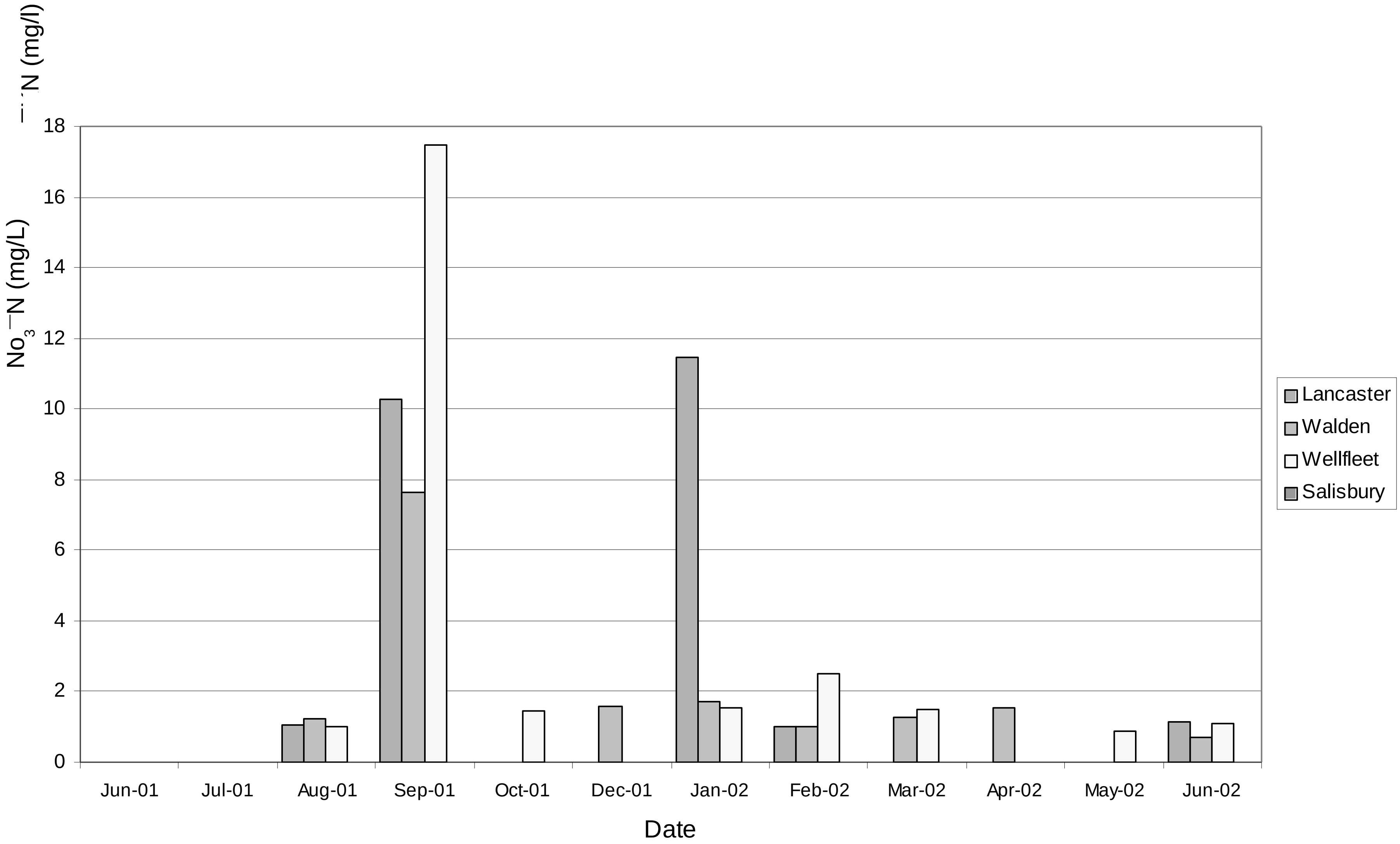


Figure 4. Nitrate (NO_3^-) content in greywater samples collected monthly state-wide.

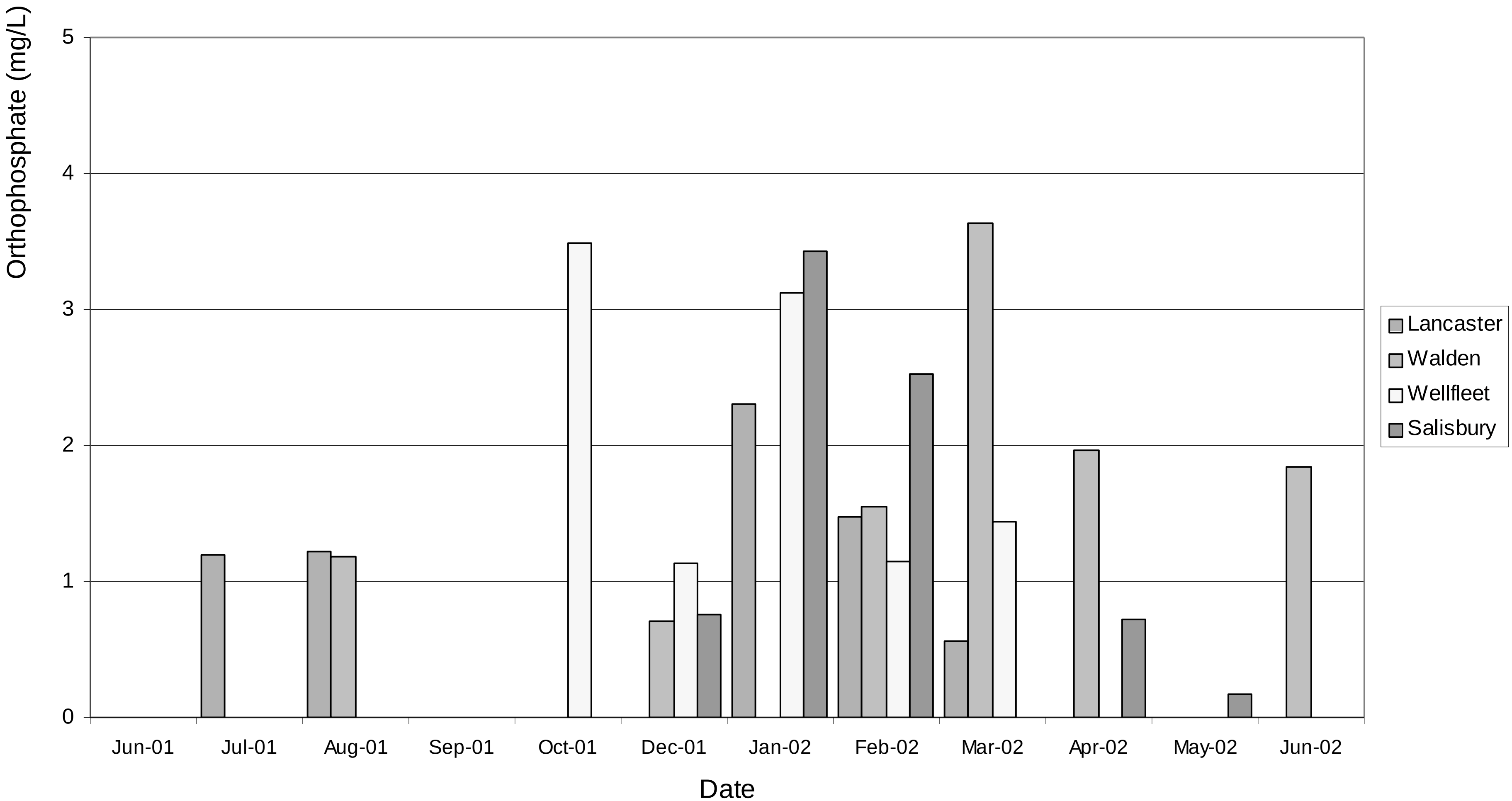


Figure 5. Orthophosphate content in greywater samples collected monthly state-wide.

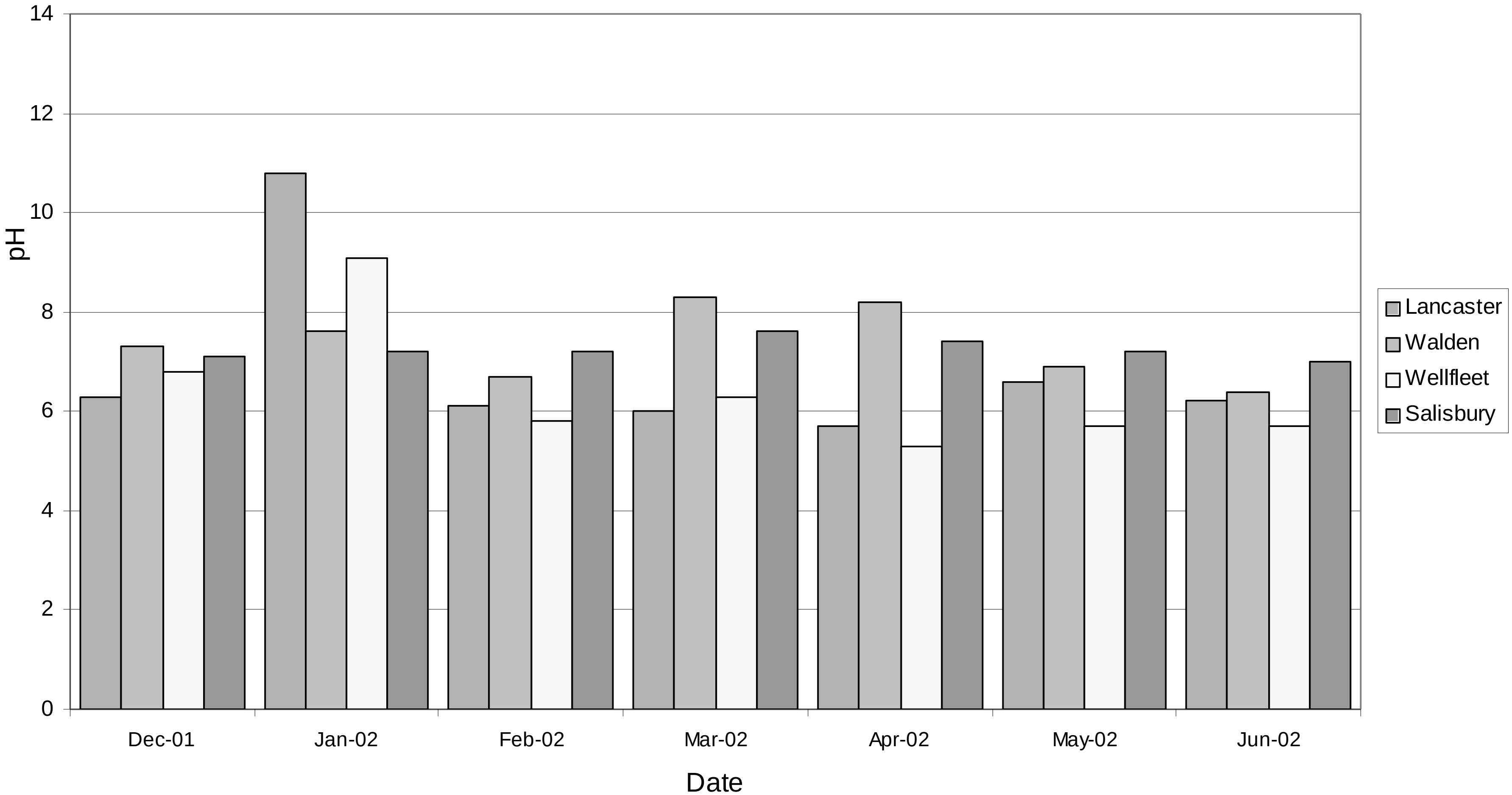


Figure 6. Variation in pH for greywater samples collected monthly state-wide.

Values for pH averaged 7.0, with a range of 5.3 to 10.8. pH values for individual sampling sites were: Lancaster 6.8 (5.7-10.8), Walden 7.3 (6.4-8.3), Wellfleet 6.4 (5.3-9.1), Minuteman 7.2 (1 sample), and Salisbury 7.2 (6.9-7.4), respectively (Fig. 6). The lower pH values may result from the use of water without any alkalinity adjustment, the mean ranges likely reflect the use of pH adjusted water, whereas the extremely high figures indicate the presence of bleach.

Monthly sampling for coliform included tests for both total coliforms (TC), fecal coliforms (FC) and E. Coli. Values for TC generally exceeded maximum countable colonies (TNTC means Too Numerous To Count) and often exceeded $>10^6$ cu/100 mL. Fecal coliforms ranged from 0 to an occasional elevated value (500-10,000 cu/100 mL). E. Coli was not detected in any of the samples. Greywater samples typically averaged between 500-2.4×10^7 TC and 170-3.3×10^3 FC per 100 mL, whereas untreated sewage has values for TC and FC of 10^5-10^6 and 10^4-10^5, respectively. The U.S. EPA guideline for FC in reclaimed water for irrigation is set at 200 cu/100 mL (Dixon et al., 1999). Jefferson et al. (2001) published data showing suggested appropriate values for domestic wastewater recycling of <10,000 and <2,000 cu/100 mL for TC and FC, respectively. Our results show that greywater samples occasionally exceed these values. This suggests that direct human contact with greywater should be avoided, unless the wastewater is disinfected.

The contents of greywater continue to vary considerable over time and by location. A gradual increase in BOD_5, TSS and TKN values can be observed during the winter. It appears that this is just a seasonal phenomenon, because more recent values are lower than the observed winter values.

Materials and Methods -Column Experiments

Column Construction

To address the question whether or not breakthrough of potential contaminants occurs under standard Title 5 loading rates, a column study was conducted. Columns were made from 6-inch (outside diameter) extruded acrylic tubing. The columns were filled with soil material compacted to a bulk density of about 1.4 g/cm^3. To avoid segregation of particles when filling the columns, the soil was added in approximately 8-inch lifts which were compacted with a flat, rubber ended rod. We used two types of soil material: a sand meeting Title 5 fill requirements with a median grain size of 0.5 mm and a uniformity coefficient <6, and a sandy loam textured soil from the Bw horizon of a Montauk (Typic Dystrudept) soil with about 4% clay and 58% sand. The bottom of each column was lined with 2.5 cm of 0.6-cm sized pea-stone to provide proper drainage and prevent clogging of the outflow spouts. The columns were then filled with either 30, 60, or 90 cm of the appropriate soil material, and covered with a 2.5-cm layer of the pea-stone to prevent swirling and crusting of the soil when the greywater was added.

The columns were secured on wooden racks and housed in a temperature controlled room set at 10^o-12^{o}C to represent average field conditions. Columns were loaded twice a day by hand at rates representing ½x, 1x, and 2x the Title 5 loading rate for each kind of soil material. For the sandy fill, loading rates were 3, 6, and 12 cm/day, respectively. For the sandy loam textured soil loading rates were 1.3, 2.6, and 5.2 cm/day, respectively. All treatments were repeated in triplicate. The greywater used was collected twice a week from the Lancaster Tourist Information Center located along Rt. 2 (west). That particular site was chosen due to its proximity to Amherst and for its large daily volume of greywater that was produced at the center. After a year of running the experiment in the above prescribed fashion, all loading rates were doubled for a month to assess whether or not breakthrough would occur when simulating field conditions where the system was reduced in size by 50% with the same volume of greywater.

Analytical Procedures

Leachate from the columns was collected and chemically analyzed on a monthly basis. Testing parameters included pH, TKN, nitrate, orthophosphate, TSS, BOD_5, and Total and Fecal Coliforms. Analytical procedures were identical to the methodology employed in the greywater characterization study with the following exceptions.

TKN. Due to the large number of samples and the expense of the reagents, we combined the samples from the three replicates of each treatment into one composite sample.

Biochemical Oxygen Demand (BOD_5). For this test we also chose to use composite samples comprised of the three replications for each treatment. Furthermore, since most of the microbial population was removed once the greywater passed through the soil columns the composite sample did not contain a sufficient amount of microbes for the BOD test. This problem was solved by seeding each sample with Polyseed BOD Seed Inoculum (InterBio, 2000). Additionally, dilutions were 0, 20, 50, and 100 mL of sample per 300 mL BOD bottle with the remainder of the bottle filled with distilled aerated water.

Coliforms. Due to the expense associated with coliform testing, only selected columns were tested on a monthly basis.

Organic Matter was determined by the loss-on-ignition method (Soil and Plant Analysis Council, 1992). Ashing was accomplished by heating the samples at 500ºC overnight.

Results and Discussion –Column Study

Effect of Soil on Greywater Treatment Efficiency

Table 1 shows mean values of the various testing parameters. The data indicate a significant reduction in all parameters, with the exception of nitrate, as compared to the applied greywater. BOD_5 values for the column samples showed an almost 15 to 25-fold reduction as compared with raw greywater, which averaged 102.0 mg/L for the Lancaster site. Table 1 shows mean BOD_5 values of 7.1 mg/L for the sand (range: 5.6-11.2 mg/L) and 3.8 mg/L for the Montauk soil (range: 2-6.8 mg/L) irrespective of column length. The data indicate that the sandy loam soil is significantly ($p<0.01$) more effective than the Title 5 sand in lowering BOD_5 (Figs. 7 and 8). The higher BOD_5 values for the sand may be in part due to short circuiting. The data indicate that higher loading rates as well as shorter columns tend to result in higher BOD_5 values in the effluent. The effect of column length was significant at the 0.05 level, but the loading rate effect was not statistically significant.

Table 1. Mean greywater constituent values in the soil columns for the period of June 1, 2001 to June 30, 2002.

Daily Loading Rate (cm/day)	**Soil Type**	**Column Length (cm)**	**BOD_5 (mg/L)**	**TSS (mg/L)**	**TKN (mg/L)**	**NO_3^--N (mg/L)**	**PO_4^{3-} (mg/L)**
3	sand	30	7.9	6	bd	8.8	bd
		60	6.9	6	bd	9.2	bd
		90	6.2	5	2.4	17.3	bd
6	sand	30	7.4	5	2	9.3	bd
		60	5.6	6	2	9	bd
		90	5.8	4	bd	9	bd
12	sand	30	11.2	6	4	4.5	bd
		60	6.6	4	2.5	12.1	bd
		90	6	5	bd	9.7	bd
1.3	s. loam	30	2	15	bd	10	bd
		60	3.4	3	bd	11.8	bd
		90	2.3	5	bd	15	bd
2.6	s. loam	30	5.4	11	2	14.2	bd
		60	2	4	bd	11.1	bd
		90	6.8	3	bd	14.5	bd
5.2	s. loam	30	5.9	5	4	9	bd
		60	2.1	4	2	14.9	bd
		90	4.4	10	2.9	15.5	bd
#sampling events			10	11	11	8	11
bd = below detection limit specified as:					<2.0 mg/L		<0.5 mg/L

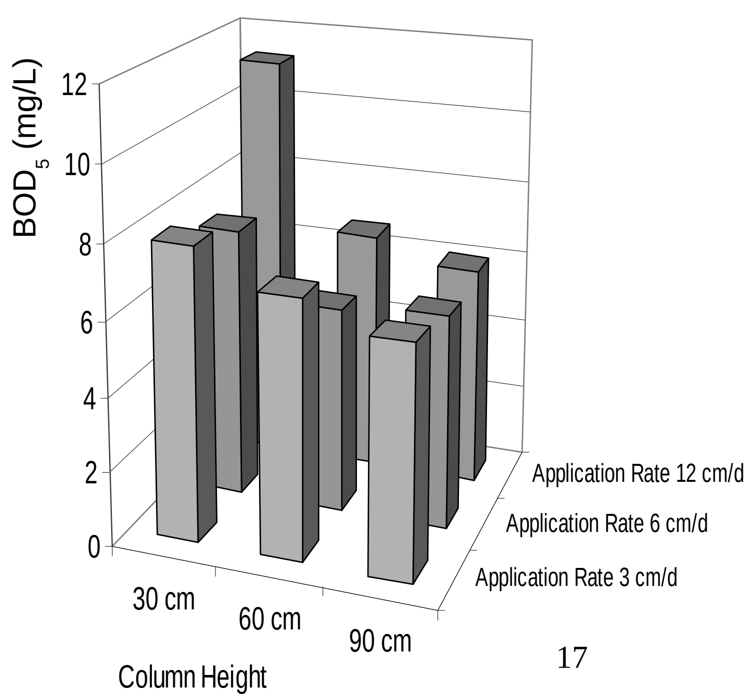


Figure 7. Biochemical oxygen demand for the Title 5 sand columns. Mean values for the period of June 1, 2001 – June 30, 2002.

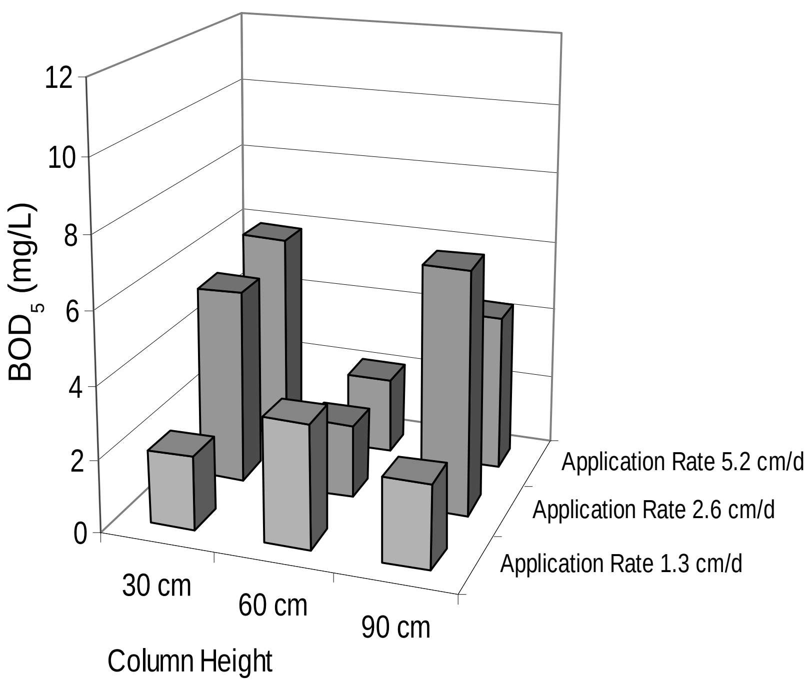


Figure 8. Biochemical oxygen demand for the Montauk soil columns. Mean values for the period of June 1, 2001 – June 30, 2002.

Total suspended solids in column effluent showed trends similar to the BOD with a 7-fold reduction in values as compared to the raw greywater (Table 1 and Figs. 9 & 10). The sand had a mean TSS value of 5.0 mg/L (range: 4-6 mg/L), the Montauk sandy loam averaged 6.0 mg/L (range: 3-15 mg/L), whereas raw greywater at Lancaster averaged 38.0 mg/L. Column length effect was significant at the 0.05 level, while the effects of soil type and dosing rate were statistically not significant, most likely because the values, although low in magnitude, show considerable variability. The slightly higher TSS values for the Montauk soils may reflect occasional suspension of soil particulate matter by percolating effluent because in some columns suspended mineral material was observed in the column effluent. This effect was not observed in Title 5 sand columns. Presence of fines in fill materials has been identified as a potential cause of system failure. The requirement to double wash Title 5 fill materials appears justified on the basis of our results.

TKN values were generally close to the detection limit of 2.0 mg/L, which is a more than a four-fold reduction as compared to the 8.1 mg/L mean for Lancaster raw greywater, This is not too surprising given the fact that most nitrogen in greywater is either in the ammonium (NH_4^+) or organic form. While percolating through the aerobic soil column some of the nitrogen may be immobilized through incorporation in the microbial mass, but by and large most of the anaerobic nitrogen will be transformed into the oxidized nitrate form. This is evident from the low TKN/NO_3^- ratios. TKN levels for the Title 5 sand ranged from <2.0-2.5 mg/L, while the range for the sandy loam was <2.0-4.0 mg/L. The highest TKN levels were found in the shortest soil columns with the highest application rates. These columns have the shortest retention time, leading to less nitrification. Statistically, only dosing rate and date proved to be highly significant ($p<0.01$), whereas the effects of soil type and soil depth were not significant.

Nitrate values increased five to six-fold as compared to raw greywater which contained about 2.0 mg NO_3^-/L. Mean value for the Title 5 sand was 9.9 mg/L (range: 1.5-23.4 mg/L) and 12.9 mg/L (range: 4.1-23.5 mg/L) for the Montauk columns (Figs. 11 and 12). The effects of soil type, column length, and sampling date were highly significant ($p<0.01$), while the effect of the application rate was statistically not significant. Nitrate values were slightly higher in the winter reflecting slightly higher TKN values in the raw greywater during that time. Within both the Title 5 sand and the Montauk soil the highest nitrate levels were found in the longest columns indicating that longer exposure times result in a higher degree if nitrification. This is also evident from the lower TKN values in the longest columns.

Orthophosphates were completely retained in the soil columns as the effluents throughout the entire testing period had PO_4^{3-} contents below the detection limit of 0.5 mg/L. Raw greywater contained little PO_4^{3-} (<0.6 mg/L) and whatever amount was present was precipitated within the soil column, most likely by iron. The low values of the column effluent therefore are no surprise.

pH levels were monitored in column effluent from January 2002 to the end of the June 2002. Six samples for pH determination were taken from similar treatments, half from each soil type. Different treatment replicates were chosen each month. The Title 5 sand had an initial pH of 6.4 and the Montauk initial pH value was 5.6. Mean pH was 6.0 (range: 5.3-7.5). In most months, pH values for the two soil types varied little, but for a couple of months (April and May) the Montauk soil had slightly higher values perhaps indicating a slightly higher buffering capacity in the Montauk soil. Both soil types showed that the soil buffering effect was greatest in the longest

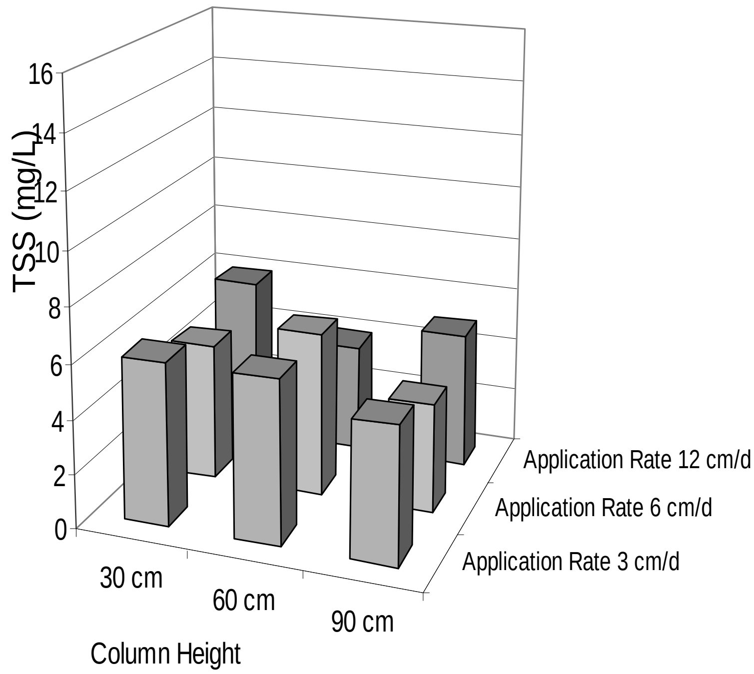


Figure 9. Total suspended solids concentration for the Title 5 sand columns. Mean values for the period of June 1, 2001 – June 30, 2002.

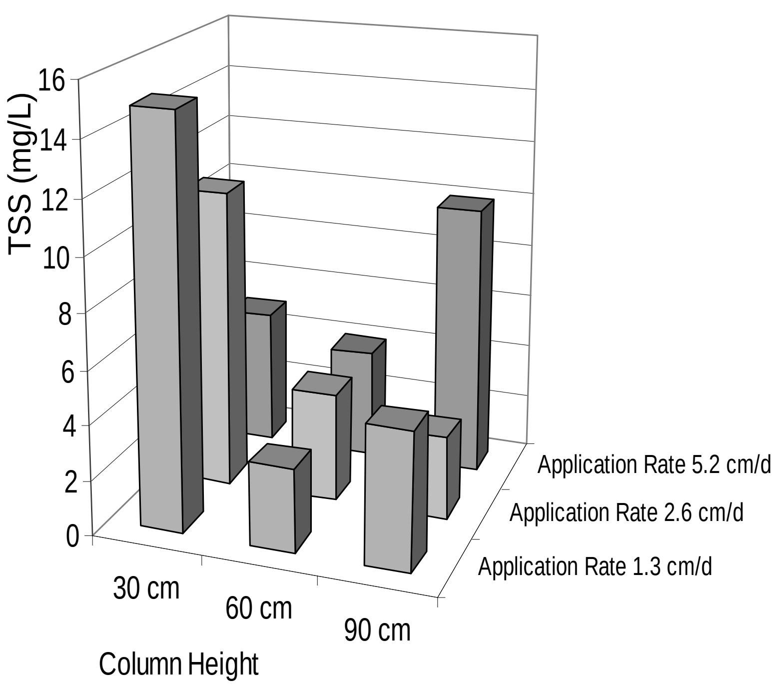


Figure 10. Total suspended solids concentration for the Montauk soil columns. Mean values for the period of June 1, 2001 – June 30, 2002.

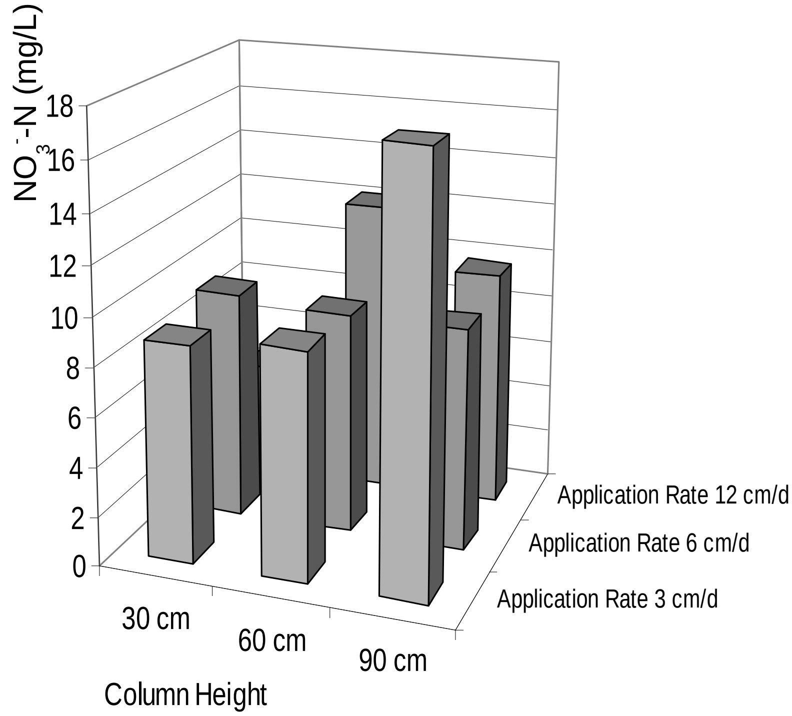


Figure 11.

Nitrate nitrogen concentration for the Title 5 sand columns. Mean values for the period of June 1, 2001 – June 30, 2002.

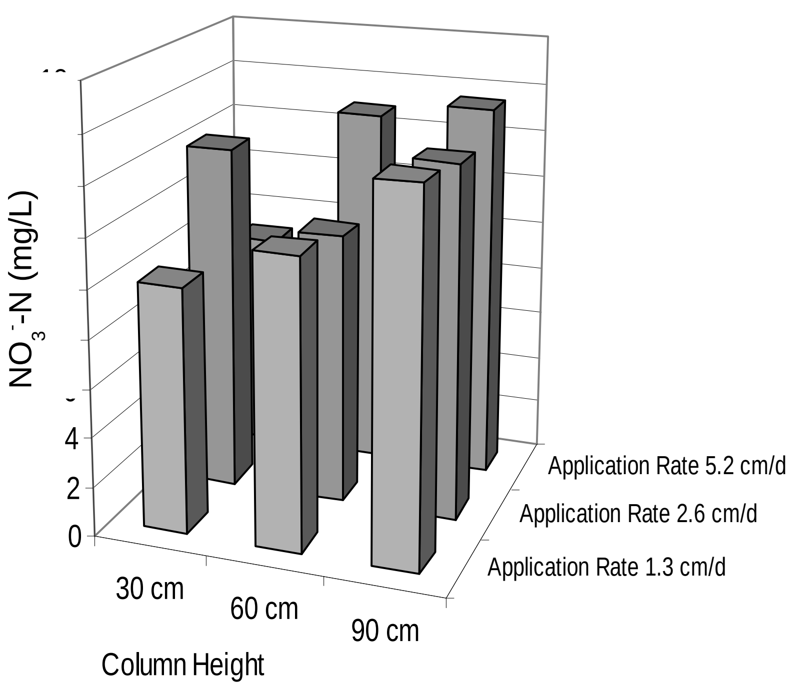


Figure 12. Nitrate nitrogen concentration for the Montauk soil columns. Mean values for the period of June 1, 2001 – June 30, 2002.

columns due increased interaction time and greater amount of surface area. For example, while the initial pH for raw sewage during January was 10.8 probably due to the use of bleach as a cleaner, the Title 5 sand in February had pH values of 7.5, 7.1, and 6.9 for the 30-, 60-, and 90-cm soil depths, respectively. Values for the Montauk soil during the same month were 7.4, 7.0, and 6.6 for the 30-, 60-, and 90-cm depths, respectively.

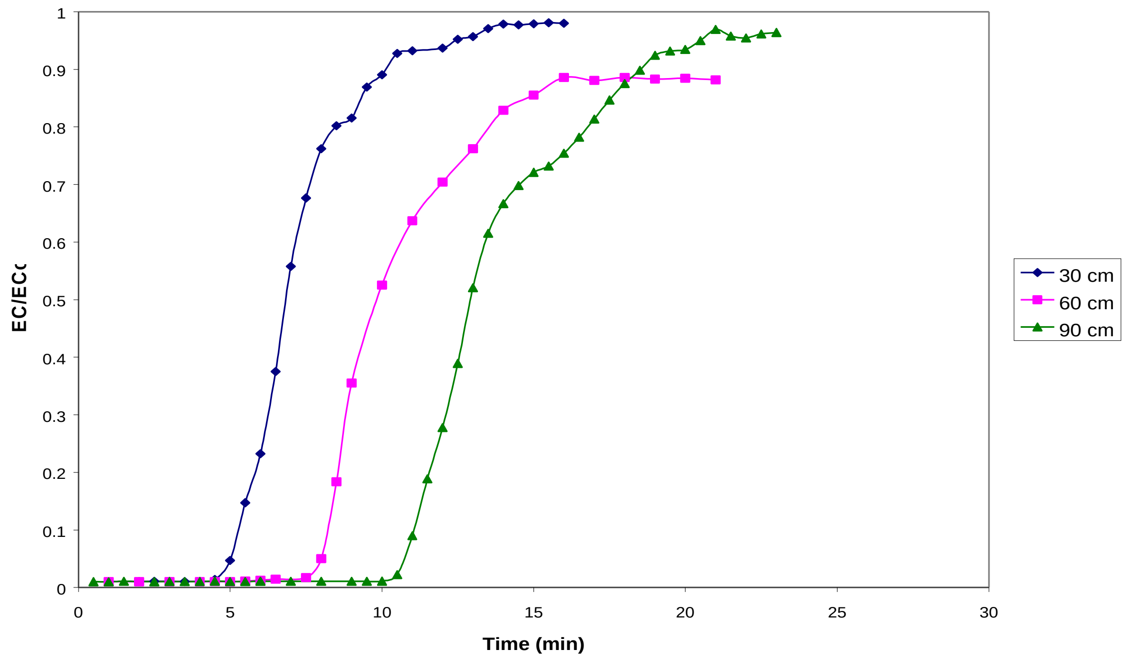
Microbial testing showed that breakthrough of total coliforms occurred on a regular basis at a rate up to 10^5 c/100 mL. This is not too surprising as these types of microorganisms occur naturally in the soil environment. Fecal coliforms, although present in greywater, generally had lower numbers in the column effluents averaging 5 cu/100 mL. Fecal Coliform values for Lancaster ranged from 0-10^4 cu/100 mL over the year of this experiment. It appears that soil is very effective in filtering microbial material from the effluent percolating through the soil. *E. Coli* was monitored during January 2002 and was not detected in any of the effluents. This indicates that soil is essential to provide proper treatment of the greywater in regards to microbial pathogens irregardless of soil column depth.

Effect of Increased Loading Rates

The column experiments were performed from June 2001 to June 2002. Upon termination of this initial experiment, loading rates for each column were doubled to assess how the soil medium would adjust to the higher amount of greywater percolating through the soil. Breakthrough of contaminants would be evidence that the soil medium is unable to handle the additional water resulting in an environmental failure. The standard chemical and physical parameters described above were measured in the column effluent 7 days and 16 days from the initial date of doubling the loading rate. BOD_5 levels remained low with a mean of 5.2 mg/L (range: 0.1-17.6 mg/L) and 5.1 mg/L (range: 1.0-22 mg/L) for Title 5 sand and the Montauk sandy loam, respectively. Mean TSS levels for the Title 5 sand and the Montauk were 4 mg/L (range: 0-23 mg/L) and 8 mg/L (0-30 mg/L), respectively. Values for TKN, along with orthophosphates, remained below their respective detection limits of 2.0 mg/L and 0.5 mg/L, respectively. Nitrate concentrations ranged from 6.2 mg/L for the Title 5 sand (range: 3-15.7 mg/L) to 5.7 mg/L (range: 2.1-10.2 mg/L) for the Montauk soil columns. Coliforms and pH displayed the same range in values as the mean values prior to doubling the loading rates. At the first testing date, 7 days after doubling the loading rate, values for most parameters were slightly higher than those at the second sampling date. Apparently, it took some time for the columns to reach steady state conditions upon doubling of the loading rate. These results indicate that higher loading rates can be accommodated without adverse effects, although only long-term experiments could answer that question beyond any doubt.

Hydraulic Performance of Soil Columns

To evaluate the possibility of changes in hydraulic properties within the soil environment, a number of columns were selected to conduct breakthrough studies under saturated conditions. The same columns were evaluated in May 2001 and June 2002. Breakthrough was evaluated by continuous application of water spiked with potassium chloride (KCl) and measuring the KCl concentrations in the effluent at selected time intervals. Breakthrough occurred considerably faster in the Title 5 sand than in the Montauk soil. Breakthrough curves for the Title 5 sand prior to application of greywater and after greywater was applied are presented in Figures 13 and 14, respectively. Breakthrough was



observed in all columns within 30 minutes, with the larger columns taking longer.

Figure 13. Title 5 break-through curves (pre-greywater dosing).

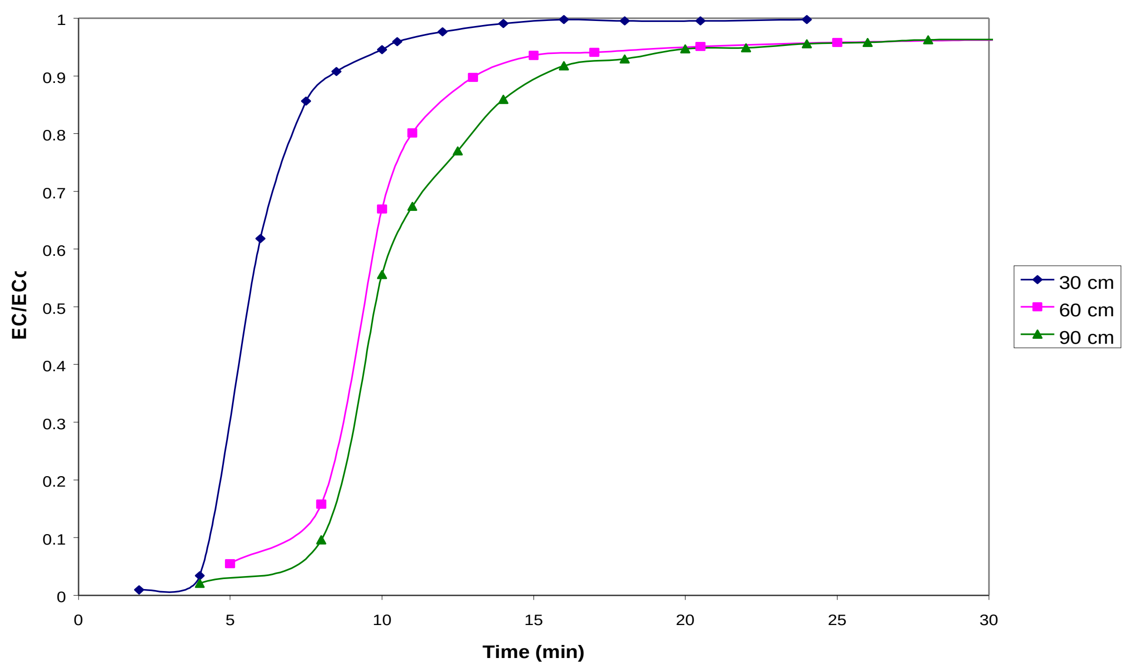


Figure 14. Title 5 break-through curves (post-greywater dosing).

Results for the Montauk were not as clear cut (Figs. 15 through 16). The higher percentage of fines in this soil causes slower percolation of fluids through the soil. Complete breakthrough for the 30- and 60-cm columns occurred after 100 and 225 minutes, respectively. The 90-cm column required about 1500 before full breakthrough occurred. After a year of greywater applications the 30-cm column took 225 minutes before complete breakthrough. There was no evidence of biomat formation, but considerable settling of soil particles was observed which could account for the slower flow rates. Similar observations were made for all columns tested.

Visual Examination of Dissected Columns

Upon termination of the experiments a number of columns, representing different treatments, were cut open length-wise to allow for visual examination of the soil to assess possible biomat formation and to facilitate sampling for bulk density and organic matter. Bulk density samples were taken from the middle portion of each column. The Title 5 sand and the Montauk soil had bulk densities of 2.0 and 1.7 g/cm^3, respectively. As compared to the original bulk density of 1.4 g/cm^3 these higher values resulted most likely from soil settling upon application of greywater as well as perhaps some movement of fines. Organic matter contents in the Title 5 sand and the Montauk soil were 1.0 and 2.5%, respectively. There was no visible evidence of biomat formation at the soil surface, nor was there any visual evidence of clay or organic matter accumulation at the bottom of the soil columns, although in some cases suspended clay particles were clearly present in the column effluent.

Conclusions

Commercial greywater contains appreciable amounts of BOD, TSS, TKN, orthophosphates, nitrates, as well indicator organisms of human pathogens, albeit at much lower concentrations than regular domestic wastewater. Average values for the parameters measured over the entire period including all sampling stations were:

Table 2. Summary of mean values and range of typical wastewater constituents as measured in the column study and compared to typical mean values for grey- and blackwater as reported in the literature.

Parameter:	**Mean:**	**Range:**	**Literature Greywater Mean:**	**Literature Blackwater Mean:**	**Soil Column Effluent Range:**
BOD_5	128.9 mg/L	22.1-358.8 mg/L	255 mg/L	280 mg/L	2 -11.2 mg/L
TSS	53 mg/L	8 -200 mg/L	155 mg/L	450 mg/L	3 -15 mg/L
TKN	11.9 mg/L	3.1- 32.7 mg/L	17 mg/L	145 mg/L	<2.0- 4.0 mg/L
NO_3^-	1.5 mg/L	<1.0- 17.5 mg/L			1.5-23.5 mg/L
PO_4^{3-}	0.9 mg/L	<0.5- 3.7 mg/L			<0.5 mg/L
pH	7.0	5.3- 10.8			5.3- 7.5
TC	too numerous to count				10^5 cu/100 mL
FC	0 – 10^4 cu/100 mL				5 cu/110 mL
E. Coli	not detected				not detected

Most measured parameters, including BOD_5, TSS, TKN, and orthophosphate, experienced a seasonal effect with higher values for January and February. This is likely due to the lower

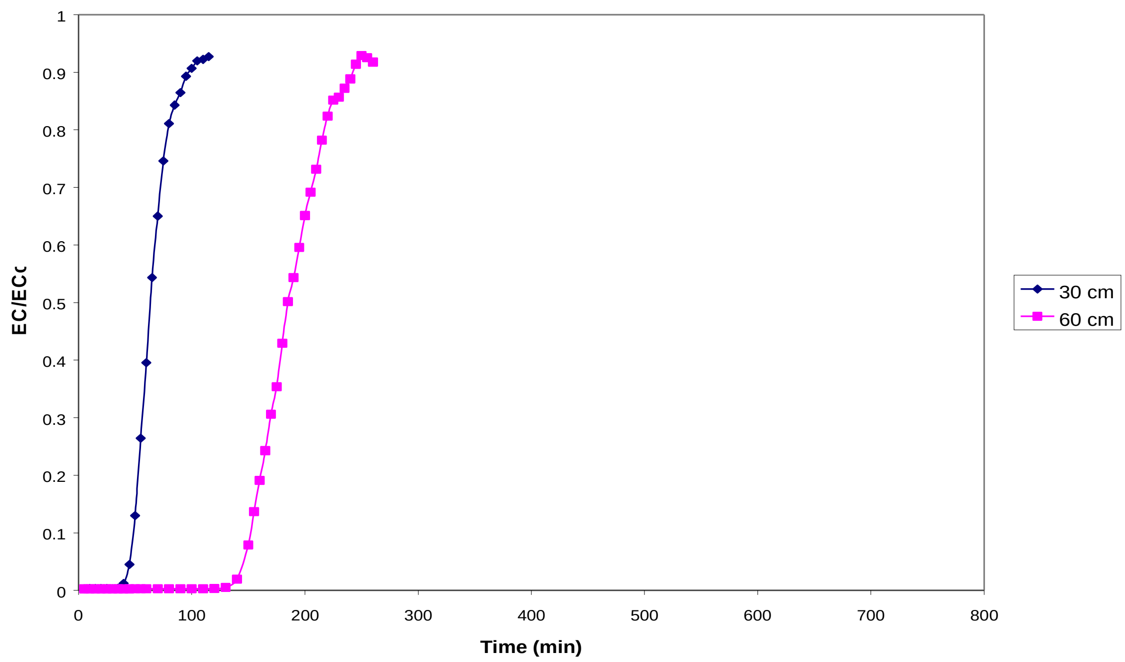


Figure 15. Montauk Bw break-through curves (pre-greywater dosing).

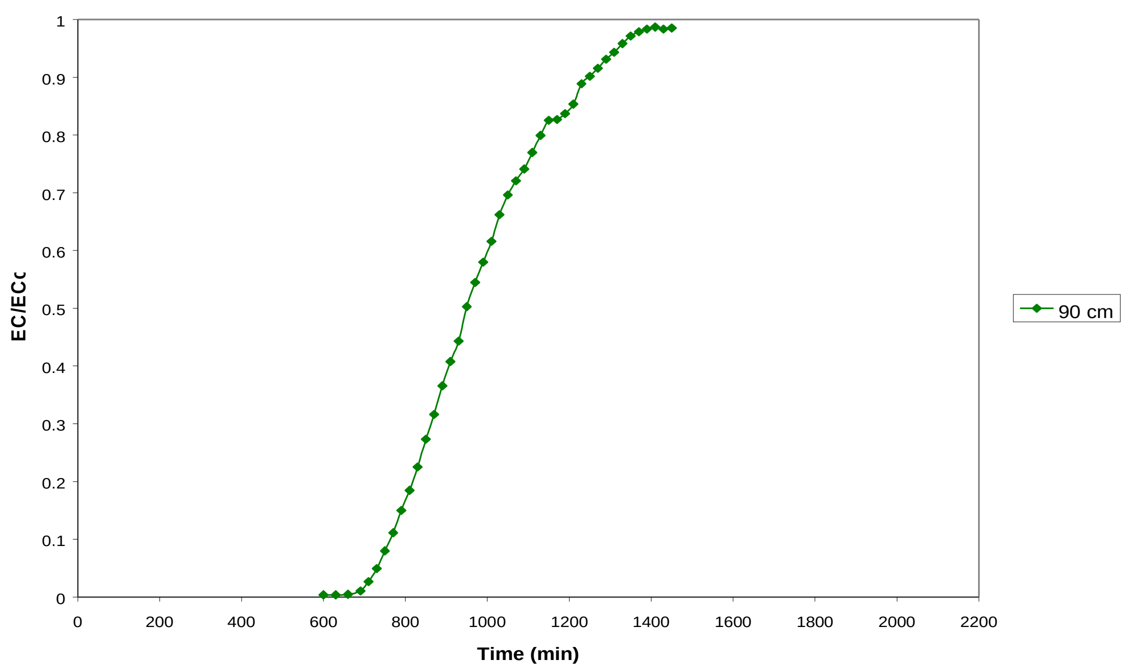


Figure 16. Montauk Bw break-through curves (pre-greywater dosing).

numbers of visitors during those months, resulting in less dilution. Nitrate and orthophosphate, generally occur in very low concentrations and do not appear to be a threat to water quality. In fact, the nitrate levels were well below that of the national drinking water standard of 10 mg/L NO_3^--N. The values that we measured are considerably lower than typical averages reported in the literature for greywater and blackwater (Siegrist, 1977). This is because we sampled greywater from commercial locations. Furthermore, in reports on domestic applications it is not always clear which wastewater generating units are included as greywater. Kitchen sinks sometimes are included, in other studies excluded which makes a big difference in reported values, particularly if the sink is equipped with a garbage disposal. High TC values are not necessarily indicative of contamination by human feces and therefore or not useful in assessing potential health threats. Fecal coliforms occasionally were present in greywater which indicates that disinfection is needed at locations where there is a chance that the liquid will come in contact with humans. Surface discharge of greywater and reuse should not be considered even with disinfection since the Department cannot be assured that disinfection will be continued. An additional problem with greywater is the odor and to a lesser extent color that was quite evident in the samples that we collected. Installation of appropriate filters in combination with subsurface disposal should circumvent any potential problems.

Our column study indicates that disposal of greywater into a soil-based medium has considerable benefits in regards to purification. Both soil types performed about evenly in regards to purifying the greywater, although the data are not totally comparable because of the different greywater application rates. Table 2 compares the parameter concentrations in greywater as well as soil column effluent. Statistical evaluation of the data indicated that BOD_5 levels are strongly affected by soil depth ($p<0.05$). Although the longer soil columns provided a higher degree of BOD removal, even the 30-cm column generated levels that remained below 12 mg/L. TSS also was strongly affected by soil depth ($p<0.05$). Orthophosphate and TKN levels were very low and often non-detectable. Most of the nitrogen was converted into the nitrate form while passing through the soil column, but values remained below 18 mg/L (3.6 mg/L NO_3^-N) in all treatments. Whereas odor was a considerable problem in raw greywater samples, after passing through just 30 cm of soil, it was minimized if detectable at all.

Our characterization data clearly indicate that greywater collected from commercial locations have much lower constituent concentrations than blackwater, or even greywater as reported in the literature. Although our values do not warrant approval for direct discharge of greywater to surface waters, it seems reasonable to apply different design standards if the greywater is disposed off through a subsurface absorption system. Our column data seem to indicate that soil depth appears significant for most of the parameters measured, whereas different application rates seem to matter less. This would mean that for commercial greywater applications credit can be given towards a reduction in size but not towards depth to the water table or flow restricting layer.

Acknowledgements

This project was funded through the Massachusetts Department of Environmental Protection with Steven Corr of the Innovative/Alternative Title 5 program, serving as the project liaison. His comments on the various draft reports are gratefully acknowledged. Most of this work was carried out by Bonnie Stewart, Master of Science candidate at the University of Massachusetts –Amherst, as part of her thesis research. We like to acknowledge the help provided by Bill Wall of Clivus New England and David DelPorto of Sustainable Strategies and Affiliates for their help in selecting the research sites. We thank the following agencies for their assistance and permission to sample each system: Mass Highway, Massachusetts Audubon Society, Massachusetts Department of Environmental Management, and the U.S. Department of the Interior. The column study was carried out at the Cold Spring Orchard, located in Belchertown, MA. The help of Joseph Sincuk, his family and farm crew is especially acknowledged. Our thanks to Mickey Spokas for her advice in regards to analytical methodology and her help to set up and dismantle the soil columns.

References Cited

American Public Health Association. 1992. Standard methods, 18th edition. Washington, DC.

Benton, J.J., Jr. 1991. Kjeldahl method for nitrogen determination. Micro-Micro Publishing, Athens, GA.

Commonwealth of Massachusetts. 1995. Title 5, 310 CMR 15.00 Massachusetts Environmental Code. Boston, MA

Dixon, A.M., D. Butler, and A. Fewkes. 1999. Guidelines fro greywater reuse: Health issues. Water and Environmental Management 15(5): 322-326.

HACH. 1992. DR/2000 Spectrophotometer handbook. HAC Company, Loveland, CO.

InterBio®. 2000. Technical service department, 9200 New Trails Drive, The Woodlands, TX

Jefferson, B, A.L. Laine, T. Stephenson, and S.J. Judd. 2001. Advanced biological unit processes for domestic wastewater recycling. Water Science and Technology 43(10): 211-218.

Siegrist, R.L. 1977. Waste segregation as a means to enhance onsite wastewater management. Journal of Environmental Health July/August: 509. *In* National Small Flows Clearinghouse, 1998, Greywater Technology Package WWBKNG82:2-6

Soil and Water Analysis Council. 1992. Handbook of reference methods for Soil Analysis Council on Soil Testing and Soil Analysis. University of Georgia Experiment Station, Athens, GA. pp. 172-173.

Stewart, B. 2003. Greywater characterization and effect of soil depth on treatment efficiency. M.S. thesis (unpublished), University of Massachusetts, Amherst, MA.

Appendix A

Numerical Data of State-wide Sampling Sites

Mean Values

Table A.1. Numerical data for state-wide sampling sites(mean values).Biochemical oxygen demand (BOD_5) values (mg/L) by site and date.

Site	**6/25/01**	**6/28/01**	**7/2/01**	**7/10/01**	**7/17/01**	**8/26/01**	**9/26/01**
Lancaster	89.1	112.3	90.7	75.2	113.6	73.1	91.5
Walden						58.1	71.7
Welfleet						36.7	78.1
Minuteman							
Salisbury							

	10/30/01	**12/6/01**	**1/10/02**	**2/5/02**	**3/12/02**	**4/5/02**	**5/13/02**
Lancaster	88.2	95	int	89	54.9	103.5	188.3
Walden	86.3	115.3	213.4	305	69.8	87.5	223.7
Welfleet	143.9	176	183.3	286.1	183.9	65.3	73.1
Minuteman	22.1	nss	nss	nss	nss	nss	nss
Salisbury		152.4	358.8	173.1	48.4	98.8	180.8

	6/10/02	**mean**	**std. dev.**	**min**	**max**
Lancaster	112.6	**102**	**33.7**	**54.9**	**188.3**
Walden	85.3	**131.6**	**84.6**	**58.3**	**305**
Welfleet	200.8	**142.7**	**77.9**	**36.8**	**286.1**
Minuteman	nss	**22.1**	**(1 obs.)**		
Salisbury	int	**168.7**	**105.8**	**48.4**	**358.8**

nss = not sufficient sample size
int = interference from sample caused non-reliable results

Table A.2. Numerical data for state-wide sampling sites(mean values). Total suspended solids (TSS) values (mg/L) by site and date.

Site	6/25/01	6/28/01	7/2/01	7/11/01	7/17/01	8/30/01	9/26/01
Lancaster	14	17	30	8	10	73	17
Walden						20	30
Welfleet						53	33
Minuteman							
Salisbury							

	10/30/01	12/6/01	1/10/02	2/5/02	3/12/02	4/5/02	5/13/02
Lancaster	30	13	173	23	17	20	23
Walden	10	23	23	23	10	23	47
Welfleet	80	33	73	80	153	67	67
Minuteman	40	nss	nss	nss	nss	200	nss
Salisbury		73	180	107	87	67	60

	6/10/02	mean	std. dev.	min	max
Lancaster	23	**38**	**47**	**10**	**200**
Walden	50	**26**	**13**	**10**	**50**
Welfleet	40	**68**	**37**	**20**	**200**
Minuteman	nss	**80**	**80**	**40**	**200**
Salisbury	67	**95**	**44**	**60**	**180**

nss = not sufficient sample size

Table A.3. Numerical data for state-wide sampling sites(mean values). Total Kjeldahl nitrogen (TKN) values (mg/L) by site and date.

Site	**6/25/01**	**6/28/01**	**7/2/01**	**7/10/01**	**7/17/01**	**8/26/01**	**9/26/01**
Lancaster	3.3	3.1	7.2	4.2	4.1	10.9	4.9
Walden						15	9.6
Welfleet						16.9	8.7
Minuteman							
Salisbury							

	10/30/01	**12/6/01**	**1/10/02**	**2/5/02**	**3/12/02**	**4/5/02**	**5/13/02**
Lancaster	13.5	7.3	int	16.8	5.4	6.6	5.4
Walden	16.5	9.7	25.1	23	12.6	int	31
Welfleet	6.9	8	10.7	4.6	13.5	7.2	10
Minuteman	5.4	nss	nss	nss	nss	nss	nss
Salisbury		8.5	30.9	24.1	4	4.9	10.5

	6/10/02	**mean**	**std. dev.**	**min**	**max**
Lancaster	4.2	**8.1**	**4.3**	**3.1**	**17.7**
Walden	21.5	**18.1**	**7.3**	**7.8**	**32.7**
Welfleet	8.6	**9.7**	**3.6**	**3.2**	**19.7**
Minuteman	nss	**5.4**	**(1 obs.)**		
Salisbury	9.5	**13.2**	**9.8**	**3.5**	**31.6**

nss = not sufficient sample size
int = interference from sample caused non-reliable results

Table A.4. Numerical data for state-wide sampling sites(mean values). Nitrate (NO_3^--N) values (mg/L) by site and date.

Site	8/26/01 *	9/26/01	10/30/01	12/6/01	1/10/02	2/5/02	3/12/02
Lancaster	1.1	10.3	bd	bd	11.5	1	bd
Walden	1.2	7.7	bd	1.6	1.7	1	1.3
Welfleet	bd	17.5	1.4	bd	1.5	2.5	1.5
Minuteman			bd	nss	nss	nss	nss
Salisbury				1.3	1.7	1.1	bd

Site	4/5/02	5/13/02	6/10/02	mean	std. dev.	min	max
Lancaster	bd	bd	1.1	**2**	**4.3**	**<1**	**14.2**
Walden	1.5	bd	bd	**1.2**	**1.5**	**<1**	**7.7**
Welfleet	bd	bd	1.1	**1.7**	**3.3**	**<1**	**17.5**
Minuteman	nss	nss	nss	**bd**	**(1 obs.)**		
Salisbury	1.2	bd	1.1	**1**	**0.6**	**<1**	**1.8**

*samples were tested at seven days after collection as opposed to within 48hrs
nss = non-sufficient sample
bd = below detection limit specified as 1.0 mg/L

Nitrate values are not present for early testing dates due to a problem with the methods. There was interference from the sample with the Cadmium Reduction Method (standard method 4500-NO3- E. Spiked levels could not be recovered. Current results were determined using the Nitrate Electrode Method (standard method 4500-NO3- D).

Table A.5. Numerical data for state-wide sampling sites(mean values). Orthophosphate (PO_4^{-3}) values (mg/L) by site and date.

Site	6/25/01	6/28/01	7/3/01	7/10/01	7/17/01	8/26/01	9/26/01
Lancaster	bd	bd	1.2	bd	1.5	1.2	bd
Walden						1.2	bd
Welfleet						bd	bd
Minuteman							
Salisbury							

Site	10/30/01	12/6/01	1/10/02	2/5/02	3/12/02	4/5/02	5/13/02
Lancaster	bd	bd	2.3	1.5	0.6	bd	bd
Walden	bd	0.7	bd	1.6	3.6	2	bd
Welfleet	3.5	1.1	3.1	1.1	1.4	bd	bd
Minuteman	bd	nss	nss	nss	nss	0.7	nss
Salisbury		0.8	3.4	2.5	bd	0.7	bd

Site	6/10/02	mean	std. dev.	min	max
Lancaster	bd	**0.6**	**0.8**	**<0.5**	**2.6**
Walden	1.8	**1.1**	**1.2**	**<0.5**	**3.7**
Welfleet	bd	**1**	**1.3**	**<0.5**	**3.6**
Minuteman	nss	**bd**			
Salisbury	bd	**1.1**	**1.3**	**<0.5**	**3.5**

bd = below detection limit specified as 0.5 mg/L
nss = not sufficient sample size

Table A.6. Numerical data for state-wide sampling sites(mean values). pH values by site and date.

Site	**12/6/01**	**1/10/02**	**2/5/02**	**3/12/02**	**4/5/02**	**5/13/02**	**6/10/02**
Lancaster	6.3	10.8	6.1	6	5.7	6.6	6.2
Walden	7.3	7.6	6.7	8.3	8.2	6.9	6.4
Welfleet	6.8	9.1	5.8	6.3	5.3	5.7	5.7
Minuteman	nss	nss	nss	nss	7.2	nss	nss
Salisbury	7.1	7.2	7.2	7.6	7.4	7.2	7

Site	**mean**	**std. dev.**	**min**	**max**
Lancaster	**6.8**	**1.8**	**5.7**	**10.8**
Walden	**7.3**	**0.7**	**6.4**	**8.3**
Welfleet	**6.4**	**1.3**	**5.3**	**9.1**
Minuteman	**7.2**	**(1 obs.)**		
Salisbury	**7.2**	**0.2**	**7**	**7.6**

nss = not sufficient sample size

Table A.7. Numerical data for state-wide sampling sites(mean values). Coliform values (cu/100 mL) by site and date.

Site	Test	6/28/01	7/3/01	7/10/01	8/26/01	9/26/01	10/30/01
Lanc	TC	TNTC	TNTC	2.0×10^{2}	TNTC	$>10^{3}$	$>10^{6}$
	FC	31	77	0	TNTC	2.0×10^{2}	TNTC
	e-Coli						
Walden	TC				TNTC	$>10^{3}$	$>10^{6}$
	FC				33	3.9×10^{3}	8.6×10^{2}
	e-Coli						
Welfleet	TC				TNTC	$>10^{3}$	1×10^{7}
	FC				20	2.0×10^{2}	3.5×10^{4}
	e-Coli						
Minuteman	TC						$>10^{6}$
	FC						9.6×10^{2}
	e-Coli						
Salisbury	TC						
	FC						
	e-Coli						

Site	Test	12/6/01	1/10/02	2/5/02	3/12/02	4/5/02	5/13/02
Lanc	TC	$>10^{8}$	1×10^{7}	2.0×10^{7}	3.0×10^{5}	1.6×10^{6}	5.6×10^{8}
	FC	1.0×10^{4}	0	5.7×10^{2}	0	0	7.1×10^{3}
	e-Coli		0	0	0	0	0
Walden	TC	$>10^{8}$	1.5×10^{6}	4.4×10^{6}	3.0×10^{5}	1×10^{5}	7.5×10^{8}
	FC	3×10^{2}	0	0	0	0	3.0×10^{2}
	e-Coli		0	0	0	0	0
Welfleet	TC	$>10^{8}$	$>10^{9}$	3.6×10^{8}	1.6×10^{7}	1.9×10^{8}	1.2×10^{8}
	FC	2.6×10^{3}	40	0	10	0	40
	e-Coli		0	0	0	0	0
Minuteman	TC	nss	nss	nss	nss	2.0×10^{5}	nss
	FC	nss	nss	nss	nss	0	nss
	e-Coli		nss	nss	nss	0	nss
Salisbury	TC	$>10^{8}$	1.4×10^{8}	1.3×10^{8}	4.0×10^{5}	1×10^{7}	$>10^{7}$
	FC	5.3×10^{2}	1.1×10^{2}	10	0	0	20
	e-Coli		0	0	0	0	0

Table A.7 continued. Numerical data for state-wide sampling sites(mean values). Coliform values (cu/100 mL) by site and date.

Site	6/10/02	min	max
Lanc	$>10^7$	2×10^2	5.6×10^8
	$>10^2$	0	$> 1 \times 10^4$
	-		
Walden	$>10^7$	$> 10^3$	7.5×10^8
	5.5×10^2	0	3.9×10^3
	-		
Welfleet	7.5×10^8	$> 10^3$	$> 10^9$
	80	0	3.5×10^4
Minuteman	nss		
	nss		
	nss		
Salisbury	1.6×10^8	4.0×10^5	1.6×10^8
	30	0	5.3×10^2
	-		

TNTC = too numerous to count (as expected with greywater samples)
**e-Coli* - broth to identify both TC and *e-Coli* was used on the samples from 1/10/02 - 5/13/02
> = greater number of coliform units than the highest dilution could account for

Appendix B

Results of ANOVA and Separation of Means for Greywater Constituent Levels

by Site and Month

Note:

Duncan's New Multiple Range Test was used to assess whether or not mean values obtained for certain parameters are statistically different at a specific probability level. In Appendix B we compared monthly mean values for each of the greywater characteristics evaluated and compared these with the overall mean. Letter designations behind the reported value indicate whether, at a certain probability level, mean values are statistically similar. For example, from Table B.1. it appears that most of the BOD_5 values measured for the Lancaster Visitor Information Center, are statistically dissimilar (as indicated by the different letters after the reported mean value), except that values for June '01, July '01, and June '02 are statistically similar at a probability level of 0.01, meaning that out of one hundred values only one may be different. The October '01 and February '02 BOD_5 values are also statistically similar as indicated by the letter "f" after the listed mean value for those months. Values for NO_3^--N appear statistically similar (they all have the letter "b" behind the reported monthly mean values with the exception of the means for September '01 and January '02 which are similar to one another, but different from the other monthly means.

Data for Minuteman could not be statistically evaluated because of the paucity of data for that location.

Table B.1. Greywater constituent concentration from June, 2001 – June 2002 for the Lancaster Visitor Information Center, Lancaster, MA

Sample Date (m-yr)	BOD_5	TKN	TSS	PO_4^{-3}	NO_3^-N
	---------- mg/L ----------				
June-01	112.3 b†	3.1 g	17 c	0 e	---
July-01	113.6 b	7.1 d	10 c	1.2 c	---
Aug.-01	73.1 g	10.9 c	73 b	1.2 c	1.1 b
Sept.-01	91.5 e	4.9 ef	17 c	0 e	10.3 a
Oct.-01	88.2 f	13.5 b	30 c	0 e	0 b
Dec. –01	95.0 d	7.3 d	13 c	0 e	0 b
Jan.-02	---	---	173 a	2.3 a	11.5 a
Feb.-02	89.0 f	16.8 a	23 c	1.5 b	1.0 b
Mar.-02	54.9 h	5.4 def	17 c	0.6 d	0 b
Apr.-02	103.5 c	6.6 de	20 c	0 e	0 b
May-02	188.3 a	5.4 def	23 c	0 e	0 b
June-02	112.6 b	4.2 fg	23 c	0 e	1.1 b
Significance	**‡	**	**	**	**

† Means within a column followed by the same letter are not significantly different according to Duncan's New Multiple Range Test.

‡ Significant at the 0.01 probability level.

Table B.2. Greywater constituent concentration from June, 2001 – June 2002 for the Walden Pond State Reservation, Walden, MA

Sample Date	BOD_5	TKN	TSS	PO_4^{-3}	NO_3^-N
	---------- mg/L ----------				
June-01	---	---	---	---	---
July-01	---	---	---	---	---
Aug.-01	58.1 h†	15.0 d	20 c	1.2 d	1.2 bc
Sept.-01	71.7 g	9.6 f	30 b	0 f	7.7 a
Oct.-01	86.3 ef	16.5 d	10 d	0 f	0 e
Dec. –01	115.3 d	9.7 f	23 bc	0.7 e	1.6 b
Jan.-02	213.4 c	25.1 b	23 bc	0 f	1.7 b
Feb.-02	305.0 a	23.0 bc	23 bc	1.6 c	1.0 cd
Mar.-02	69.8 g	12.6 e	10 d	3.6 a	1.3 bc
Apr.-02	87.5 e	---	23 bc	2.0 b	1.5 b
May-02	223.7 b	31.0 a	47 a	0 f	0 e
June-02	85.3 f	21.5 c	50 a	1.8 b	1.0 cd
Significance	**‡	**	**	**	**

† Means within a column followed by the same letter are not significantly different according to Duncan's New Multiple Range Test.
‡ Significant at the 0.01 probability level.

Table B.3. Greywater constituent concentration from June, 2001 – June 2002 for the Wellfleet Bay Wildlife Sanctuary, Wellfleet, MA

Sample Date	BOD_5	TKN	TSS	PO_4^{-3}	NO_3^-N
	---------------------------------- mg/L --				
June-01	---	---	---	---	---
July-01	---	---	---	---	---
Aug.-01	36.7 i†	16.9 a	53 bcd	0 e	1.0 c
Sept.-01	78.1 f	8.7 cd	33 d	0 e	17.5 a
Oct.-01	143.9 e	6.9 de	80 b	3.5 a	1.4 c
Dec. –01	176.0 d	8.0 cd	33 cd	1.1 d	0 d
Jan.-02	183.3 c	10.7 c	73 bc	3.1 b	1.5 c
Feb.-02	286.1 a	4.6 e	80 b	1.1 d	2.5 b
Mar.-02	183.9 c	13.5 b	153 a	1.4 c	1.5 c
Apr.-02	65.3 h	7.2 de	67 bcd	0 e	0 d
May-02	73.1 g	10.0 c	67 bcd	0 e	1.0 c
June-02	200.8 b	8.6 cd	40 cd	0 e	1.1 c
Significance	**‡	**	**	**	**

† Means within a column followed by the same letter are not significantly different according to Duncan's New Multiple Range Test.
‡ Significant at the 0.01 probability level.

Table B.4. Greywater constituent concentration from June, 2001 – June 2002 for the Salisbury Visitor Information Center, Salisbury, MA

Sample Date	BOD_5	TKN	TSS	PO_4^{-3}	NO_3^-N
	---------------------------------- mg/L --				
June-01	---	---	---	---	---
July-01	---	---	---	---	---
Aug.-01	---	---	---	---	---
Sept.-01	---	---	---	---	---
Oct.-01	---	---	---	---	---
Dec. –01	152.4 d†	8.5 d	73 bc	0.8 c	1.3 b
Jan.-02	358.8 a	30.9 a	180 a	3.4 a	1.7 a
Feb.-02	173.1 c	24.1 b	107 b	2.5 b	1.1 cd
Mar.-02	48.4 f	4.0 e	87 bc	0 d	0 d
Apr.-02	98.8 e	4.9 e	67 bc	0.7 c	1.2 bc
May-02	180.8 b	10.5 c	60 c	0 d	0 d
June-02	---	9.5 cd	67 bc	0 d	1.1 cd
Significance	**‡	**	**	**	**

† Means within a column followed by the same letter are not significantly different according to Duncan's New Multiple Range Test.
‡ Significant at the 0.01 probability level.