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Nutrient and Microbial Movement from Seasonally-Used Septic Systems

Frank B. Postma, Arthur J. Gold and George W. Loomis

Abstract

Unsewered seasonal vacation communities present unique problems for on-site sewage disposal. Seasonal occupancy may promote the transmission of contaminants to groundwater due to incomplete formation of a biological clogging mat in the soil absorption system. Groundwater surrounding three seasonally-used septic systems was monitored to determine the movement and attenuation of nitrogen, phosphorus and two bacterial indicators of human fecal contamination, fecal coliforms and Clostridium perfringens. Nitrate-N concentrations were often three to four-fold greater than the drinking water standard at wells 6 m from the soil absorption systems. Minimal phosphorus migration occurred from these systems. Although more than 1.5 m of unsaturated soil separated the bottom of the soil absorption system from the groundwater, elevated numbers of both bacterial indicators were observed in groundwater at both 2 m and 6 m away from the absorption systems. Biological clogging mats, which are considered to be critical for even distribution of wastewater within a drainfield, were not found when the systems were excavated at the end of summer occupancy. Siting seasonally-used shoreline septic systems may require improved effluent distribution to achieve wastewater renovation.

Unsewered lakeside or coastal vacation communities usually rely on on-site sewage disposal systems (septic systems) to treat household wastewater and to protect the quality of surface water and groundwater. The inherent proximity of beach communities to surface and groundwater coupled with the frequent placement of septic systems on sites with high groundwater tables and permeable, coarse sands developed from beach sediments suggests the potential for incomplete on-site wastewater treatment. Another factor which may alter the efficiency of on-site wastewater treatment is the seasonal summer use of the systems, rather than continuous year 'round use typical of most residences.

A conventional septic system relies on a septic tank to settle solids and a gravity-fed soil absorption system (either a trench or bed type design) to treat and dispose of the clarified effluent (1). After eight to 15 months of continuous wastewater input, a conventional soil absorption system develops a biological clogging mat of reduced permeability at the interface between the native soil and the constructed absorption system (2). This clogging mat promotes uniform distribution of effluent throughout the field, thereby increasing reactive surfaces, interaction time and the system's ability to filter pollutants. In sandy soils, a clogging mat slows effluent movement into the soil and creates unsaturated, aerobic soil conditions as the effluent percolates to the groundwater. Removal of bacteria, protozoa, viruses and phosphorus appears to be enhanced by the conditions clogging mats create (3, 4).

For septic systems serving individual homes, contamination of groundwater has often been observed where saturated soil conditions exist at or near the depth of the absorption field (5, 6, 7). Groundwater contamination has also been documented in situations where uneven wastewater distribution caused elevated effluent loadings to selected portions of the absorption field (8). In porous soils without a clogging mat, effluent can leave the drainfield at localized regions. This concentrated hydraulic loading can promote a condition termed "fingering", where channelized, partially saturated flow allows effluent to travel rapidly through the unsaturated soil with little treatment before reaching the groundwater (2, 9, 10). Given that seasonal waterfront communities are occupied primarily during the summer months and remain inactive during much of the year, formation of a clogging mat seems unlikely.

The objective of this research project was to determine the migration and attenuation of two microbial indicators, fecal coliform and *Clostridium perfringens* and two nutrients, nitrogen and phosphorus, from seasonally-used septic systems. A second objective was to determine if a clogging mat capable of promoting uniform distribution developed during the system's period of seasonal use. The results of this study should aid in establishing recommendations for future designs in seasonal lake front or coastal communities.

Site selection

Three seasonally-used conventional septic systems were selected for detailed study. Potential study sites were first delineated based upon the following geologic criteria: 1) coarse grained outwash or beach soils; and 2) unconfined piezometric surface (groundwater table) within 2 meters of the ground surface. Final site selection was determined by requiring that all septic systems meet modern design standards (11), that the homes be seasonally occupied and that the sites receive negligible nutrient and bacterial inputs from other sources. Three suitable sites (identified as Sites K, M and S) were found on a barrier spit complex between open ocean and a coastal lagoon in Charlestown, Rhode Island.

Overall development density in the immediate vicinity of the study area ranged between 0.1 and 0.4 hectares. The selected sites ranged in size from 0.5 to 1.2 hectares. Because of shallow water tables, the entire elevation of the building lot (excluding wetland areas) at each site was raised approximately 1 meter by the addition of poorly sorted gravelly sand fill material. The septic systems at each site were installed directly in this fill material in accordance with Rhode Island regulations (11). The native beach sediments underlying this imported fill material consisted of well sorted medium sands. Various characteristics of the three septic systems used in this study are shown in Table 1.

Groundwater tables, as determined by depth to free water, were 1.6 to 1.7 meters below the bottom of the absorption trenches at all sites. The ages of the systems ranged from seven to 10 years, which negated any

Table 1
Characteristics of the seasonally-used septic systems at the study sites

Parameter	Septic system K	M	S
Construction date	1979	1982	1978
Drainfield configuration	trenches	bed	bed
Occupants/home	6	6	4
Effluent flow rate (lpd)*	1020	1020	680

*lpd - liters per day; estimate based on 170 liters/person/day

variations due to initial start up of the systems. The sites selected proved to be particularly advantageous due to the absence of lawns, agriculture and domestic animals; therefore, all pollutant additions to the groundwater could be directly related to septic system inputs.

Site instrumentation

A groundwater monitoring well instrumentation plan was devised to intersect groundwater contaminants originating from each septic system. Initially, 16 wells were placed in two concentric rings around each soil absorption system. With the start of summer occupancy and the first detection of contamination plumes, additional groundwater monitoring wells were added in the apparent areas of contamination. A total of approximately 20 wells were installed at 2 and 6 meter distances away from the soil absorption systems at each home.

Monitoring wells were constructed of 3.3 meter lengths of 5 cm PVC pipe, equipped with plastic well points and perforated along the lower half. Wells were installed to a depth of 1 meter below the water table. Bentonite seals were placed around the wells to prevent surface water from channeling down the well casing. To discourage tampering, the wells were secured at ground level with standard PVC threaded female adapters and punctured inverted male caps. The wells were then covered with ventilated well covers to prevent dust contamination. Plywood risers were also installed around the distribution box (D-Box) of each system in order to obtain untreated effluent samples. A D-Box is a concrete manifold located between the septic tank and soil absorption system and functions to evenly distribute effluent throughout the soil absorption system (1).

Groundwater monitoring was conducted at all three sites from March through October, 1988. Sampling was conducted monthly during the off-season period between March 1 and May 31, 1988. During the period of continuous summer use (June 1 to October 1), biweekly sampling occurred.

Water analysis

Groundwater was sampled in two steps. Samples were first collected from all groundwater wells and analyzed within 12 hours for nitrate-N, the ion selected to trace the wastewater plume in the groundwater. Monitoring wells with nitrate-N concentrations elevated above background levels (defined as greater than 2 mg/l) were then resampled within 24 hours for analysis of microbial indicators and total phosphorus. In both sampling steps, three well volumes of water were evacuated prior to sample extraction to ensure representative samples of the groundwater. To monitor input levels of total nitrogen and total phosphorus to the soil absorption system, the D-Box was also sampled at this time. Samples of D-Box effluent were not taken for analysis of microbial indicators.

In step 1 samples were then collected into acid washed polyethylene plastic bottles and analyzed for nitrate-N using the high pressure liquid chromotography method (12). Protocol for water analysis by high pressure liquid chromotography included the microfiltration (0.4 um) of all samples, dilution or duplication of 30 percent of the collected samples, and calibration of the instrument both at the beginning and end of each sampling set to assure integrity of the results.

In step 2, 500-milliliter samples were collected for microbial analysis using separate sterilized polyethylene tubing and glass bottles for each well to prevent any cross-contamination. Microbial samples were stored at 4°C for no more than six hours to ensure the integrity of the results. Samples were analyzed within this six hour period for fecal coliforms and *C. perfringens*. The membrane filter technique was employed for bacterial enumeration using media and methods described by APHA (13) and Bisson and Cabelli (14).

The total phosphorus analysis of well and D-Box samples followed the persulfate digestion method (13), with phosphate determination by the colormetric ascorbic acid reduction method (15). Total Kjeldahl nitrogen analyses of D-Box samples were determined by the block digestion method followed by ammonium-nitrogen determination (13, 16). At each site, the grain size distribution of the fill material and the native soil was determined using the sieve method.

Results

All three of the absorption systems monitored in this project were installed in an imported fill material that differed markedly from the native underlying beach sediments in grain size distribution. Fill materials tended to be relatively poorly sorted gravelly medium to coarse sands with a mean effective diameter (D_{10}) of 0.11 mm (range 0.08 - 0.12 mm) and a mean uniformity index of 9.1 (range 6.6 - 13.3) for the three sites. The native beach sediments were well sorted, medium sands with a mean uniformity index of 2.3 (range 2.0 - 2.8) and a mean effective diameter of 0.24 mm(range 0.16 - 0-.30 mm). Saturated hydraulic conductivity was estimated from the grain size distribution and found to be 4.75 m/day (range 2.88 - 7.20 m/day) for the fill material and 11.76 m/day (range 8.64 - 15.12 m/day) for the native material (17).

Nitrogen

Nitrate-N was used to identify the plume of septic system effluent in the groundwater at each site. Most studies have demonstrated that nitrogen is not substantially removed within the septic tank and soil absorption components of a conventional septic system. As septic tank effluent enters the soil absorption system, the nitrogen is rapidly converted to nitrate-N under the aerobic conditions associated with properly sited and functioning drainfields. Once in the groundwater, nitrate-N is expected to be relatively conservative, with reductions in concentrations attributed primarily to dilution and dispersion. Other studies of septic system contamination have used elevated chloride concentrations to trace effluent plumes. Because of the ocean front location of the sites in this study, however, background chloride concentrations in groundwater were comparable to chloride concentrations in septic system leachate, negating the use of this ion as a tracer. Background groundwater concentrations of nitrate-N at the sites were less than 2 mg/L, while septic tank effluent concentrations of total nitrogen averaged 101 mg/L (range 83-115 mg/L) for the three sites.

The regional groundwater flow patterns of barrier beaches located between coastal ponds and open oceans have been

Table 2
Maximum concentrations of nitrate-N in groundwater surrounding seasonally-used septic systems

Distance from septic system m	Nitrate-N concentrations 1988									
	May 17	June 1	June 13	June 28	July 11	July 25	Aug 9	Aug 22	Sept 6	Sept 19
				mg/l						
Site K										
2	ND[a]	ND	ND	ND	3.0	115.5	23.1	58.2	17.5	48.1
6	ND	ND	ND	ND	ND	41.0	8.2	8.3	3.7	48.4
Site M										
2	0.8	ND	ND	ND	7.8	43.7	16.0	31.2	73.8	3.1
6	1.8	2.4	1.9	1.9	0.8	2.0	36.5	5.9	24.5	51.5
Site S										
2	1.1	2.3	4.6	1.9	18.1	24.1	25.4	6.3	19.2	45.4
6	1.5	1.5	1.9	1.9	5.0	30.7	39.0	28.5	35.1	37.0

[a]ND = samples below detection limit of 0.1 mg/l. Underlining denotes occupied period.

found to be very dynamic, with the direction of flow shifting due to seasonal changes in pond water levels, well pumping and storm and tidal processes. Because of the difficulties in determining regional groundwater flow directions, background nitrate-N concentrations were determined from wells within the sampling network which did not change markedly from the spring non-occupancy period. Based on spring sampling, a threshold concentration of 2 mg/L was chosen to denote wells contaminated above background levels.

The pre-occupation period for each home varied slightly; however, all homes were occupied continuously from July 11 until September 6, with the exception of site K which was continuously occupied until September 19. Background nitrate-N concentrations established during the preseason generally ranged from less than 0.1 (the detection limit) to 2 mg/L. Nitrate-N concentrations greater than 2 mg/L were observed infrequently during the pre-occupation period, corresponding to the intermittent weekend use of the homes. Once continuous occupation commenced, elevated nitrate-N levels were evident in the groundwater at each of the investigated sites and continued for the entire occupied season (Table 2).

Only a portion of the monitoring wells had elevated nitrate-N concentrations, indicating that effluent was moving from the systems as a plume rather than as a broad even zone of input. Generally, plume direction remained constant throughout the occupancy period. To analyze contaminant movement, the data presented at each distance are the concentrations within the plume, rather than the mean concentrations of all wells at a given distance from the drainfield. Mean concentrations at a set distance would include sites not affected by septic leachate and would underestimate the influence of the septic systems on groundwater quality. Table 2 displays the maximum concentrations of nitrate-N as a function of distance throughout the sampling period.

The highest concentrations of nitrate-N found in 2 meter wells during the occupied season were in close proximity to the D-Box. Based on the pattern of contaminated wells, septic tank effluent appeared to be concentrated within the absorption system at a point near the D-Box, rather than distributed evenly throughout the system. This uneven distribution may be related to clogging mat development. No clogging mat was observed at sites K or S at the end of the period of summer occupancy, when the three systems were excavated to observe the condition of the biological clogging mat. Site M was the only home which appeared to be developing a clogging layer. An observable, very weakly-defined black coating on some grains within the soil absorption system was the only indication of any collection of septic fines. Contamination at site M was limited to wells adjacent to the D-Box, suggesting minimal distribution within the absorption system.

Microbial indicators

Bacterial assays of nitrate-N contaminated wells showed a high level of microbial contamination in close proximity to the soil absorption systems throughout the occupancy period (Tables 3 and 4). Elevated levels of fecal coliform contamination were detected at the 6 m wells of each site within two weeks after habitation commenced. No data were obtained on fecal coliforms in the septic tank effluent of the sites; however, values obtained from Reneau and Pettry (4), EPA (1) and Cogger et al. (7) reported fecal coliform concentrations of approximately 10^6 MPN (most probable number) / 100 ml water in septic tank effluent. Median fecal coliform counts obtained from 2 meter wells at each site ranged from 49 to 214 cfus (colony forming units) / 100 ml throughout the period of occupancy. These values indicate that although estimated reductions of four orders of magnitude were observed, the drainfield alone was not completely adequate in removing the fecal coliform indicators.

Cogger et al. (7) found that fecal coliform removal through beach and outwash sands increased as the depth of the unsaturated zone increased. They found that with 60 cm of unsaturated soil, fecal coliform counts in shallow wells 1.5 m from a drainfield were less than 25 MPN / 100 ml. The results of Cogger et al. (7) were obtained from a soil absorption system that received uniform dosing throughout the system via low pressure distribution pipes.

The high fecal coliform counts observed from seasonally occupied systems in this present study, occurred with unsaturated depths of 1.6 meters, consistently deeper than Cogger et al. (7) reported. The incomplete removal noted at the 2 m

Table 3
Maximum concentrations of fecal coliforms in groundwater surrounding seasonally-used septic systems

Distance from septic system m	Fecal Coliforms 1988							
	June 13	June 28	July 11	July 25	Aug 9	Aug 22	Sept 6	Sept 19
Site K			cfu[a] / 100 ml					
2	8.0	11.0	156.0	274.0	132.0	214.0	217.0	NM[b]
6	OP[c]	0.0	0.0	7.0	6.0	2.5	1.0	NM
Background[d]	3.0	0.0	0.0	0.0	0.0	2.0	1.0	0.0
Site M								
2	0.0	4.0	227.0	0.0	31.2	23.0	56.0	3.5
6	0.0	1.0	84.0	21.0	2.0	101.0	137.5	141.0
Background	3.0	1.0	1.0	0.0	0.0	3.0	1.5	1.0
Site S								
2	32.0	53.5	48.8	450.0	39.0	27.0	65.0	0.0
6	66.8	28.0	66.6	97.5	5.5	41.1	79.0	0.0
Background	0.0	2.0	0.0	5.5	2.0	0.0	4.0	4.0

[a]cfu = colony forming units
[b]NM = not measured
[c]OP denotes those wells outside of nitrate-N plume.
[d]Background represents analysis of non nitrate-N contaminated wells.
Underline denotes occupied period.

groundwater wells may have resulted from the poor distribution of effluent through the drainfields monitored. Without a developed clogging mat or uniform effluent dosing, rapid channelized flow is expected through the unsaturated soil, minimizing bacterial removal.

Movement of *C. perfringens* in the groundwater roughly mimicked the trends of the fecal coliforms (Tables 3 and 4) with elevated counts observed at the sites within two weeks of habitation. Although no data were obtained on *C. perfringens* in septic tank effluent in this study, Bisson and Cabelli (14) found concentrations of 1×10^5 cfu / 100 ml in septic tank effluent. As with the fecal coliform results, this suggests that massive reductions of *C. perfringens* occurred within the unsaturated zone and first 2 meters of saturated flow. At site K, *C. perfringens* was routinely found at 6 m wells while fecal coliforms were not detected in the plume, corroborating other studies which have found that *C. perfringens* is a superior tracer of domestic wastewater due to the ability of the *C. perfringens* spores to resist environmental degradation (18).

As shown in Table 3, fecal coliform concentrations a sites M and S were often in excess of the marine recreational water standard of 50 cfu / 100 ml (19) at 6 meters and remained in excess of the EPA (20) drinking water standard (<1 cfu / 100 ml) throughout the entire occupied period. A one tailed paired comparison T test was run on dates when the systems were occupied to test the hypothesis that bacterial counts were significantly reduced from 2 m wells to 6 m wells (21). Site K demonstrated a statistically significant decrease ($P < 0.05$) in both fecal coliform and *C. perfringens* contamination with distance. Neither sites M or S had a significant decrease in either bacterial parameter, indicating that removal of these microbial indicators was minimal within the groundwater at these two sites.

Phosphorus

Several authors (8, 22, 23) have found that in sandy soils the potential exists for significant groundwater phosphorus contamination. In this study, phosphorus was found in the groundwater plumes of all three systems. As shown in Table 5, total phosphorus concentrations as high as 4.73 mg/l were detected in the 2 meter wells. The consistently high concentrations observed at site S suggest that fingering may have occurred and that limited treatment of the septic effluent was occurring before reaching the groundwater. The average total phosphorus concentration of septic tank effluent was 13.0 mg/l for the three sites during the summer occupancy period. At sites K and S, where the highest degree of phosphorus contamination was detected, concentrations diminished rapidly with distance. At all sites concentrations at the 6 m wells were usually comparable to background levels.

Given the limited contact time expected in these coarse textured soils, phosphorus removal is most likely due to what Lance (24) termed "fast interactions", whereby phosphorus is removed by surface adsorption onto soil particles independent of loading rate. Once the "fast reaction" soil adsorption sites had been occupied (as would be the case once fingering had occurred), significant quantities of phosphorus would be left in solution and be capable of migrating to the groundwater (7, 25). During the off-season, "slow reaction" phosphorus sorption would occur and dominate along with reactivation of sorption sites, allowing for further treatment of phosphorus the following year. Reactivation of phosphorus adsorption sites has been documented and may explain the one to two month lag period between nitrate-N and phosphorus movement in groundwater, thus limiting phosphorus contamination of the groundwater to the latter part of the occupied season (26, 27). Resting the drainfield during the off-season would con-

Table 4
Maximum concentrations of *Clostridium perfringens* in groundwater surrounding seasonally-used septic systems

Distance from septic system m	*Clostridium perfringens* 1988 June 13	June 28	July 11	July 25	Aug 9	Aug 22	Sept 6	Sept 19
				cfu[a] / 100 ml				
Site K								
2	0.0	0.0	229.5	118.5	103.0	422.0	501.0	NM[b]
6	0.0	2.0	22.0	28.5	92.0	35.2	27.0	33.5
Background[c]	1.0	0.0	0.0	0.5	1.0	0.0	0.0	0.0
Site M								
2	19.0	0.0	12.0	411.0	55.5	131.0	211.0	283.0
6	19.5	11.0	21.0	65.0	442.0	274.0	63.5	NM
Background	1.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
Site S								
2	29.5	11.0	130.0	116.0	103.5	31.0	74.3	91.0
6	3.5	39.0	26.0	254.0	273.5	97.0	187.5	NM
Background	0.0	0.0	0.5	0.0	0.0	0.0	1.0	0.0

[a]cfu = colony forming units
[b]NM = not measured
[c]Background represents analysis of non nitrate-N contaminated wells.
Underline denotes occupied period.

ceivably permit regeneration of phosphorus adsorption sites to occur.

Conclusions and recommendations

The results of this study indicate that incomplete treatment of wastewater can occur from septic systems serving seasonally-used homes, even when substantial depths of unsaturated soil separate the absorption system from the groundwater. Clogging mats did not form in the soil absorption systems and may have contributed to heavy loading of effluent in selected portions of the absorption fields, thereby reducing treatment through the unsaturated zone. Levels of bacterial indicators frequently exceeded recreational water standards in groundwater 6 meters from the absorption systems. As expected, concentrations of nitrate-N were not lowered below drinking water standards by the systems. Minimal migration of phosphorus occurred; a result of the soil characteristics and intermittent use.

Since no comparisons to continuously occupied homes were conducted during this study, it is difficult to separate the influence of seasonal use from site factors when reviewing the results. However, we believe that shoreline systems need to be designed to function efficiently regardless of occupancy patterns. Improved distribution of effluent throughout the soil absorption system can be promoted through the addition of low pressure pipe systems (6). Installation of a sand filter prior to effluent discharge into a soil absorption system would provide an additional treatment step in removing microbial pollutants. Our study suggests that both even distribution and an adequate separation depth to groundwater must be incorporated into the design and siting of shoreline septic systems.

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Table 5
Maximum phosphorus concentrations in groundwater surrounding seasonally-used septic systems

Distance from septic system m	Total phosphorus concentrations 1988									
	May 17	June 1	June 13	June 28	July 11	July 25	Aug 9	Aug 22	Sept 6	Sept 19
				mg/l						
Site K										
2	OP[a]	0.03	OP	OP	0.02	0.08	0.19	3.88	0.08	1.06
6	0.01	OP	0.01	0.01	OP	0.01	0.01	0.01	0.01	0.02
Background[b]	OP	OP	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Site M										
2	0.24	OP	0.01	OP	0.04	0.02	0.07	0.09	0.28	0.02
6	0.04	0.01	0.01	0.04	OP	0.05	0.10	0.26	0.01	0.29
Background	0.01	0.01	0.01	0.01	0.04	0.01	0.04	0.01	0.04	0.04
Site S										
2	0.65	1.93	0.40	0.48	0.93	2.70	2.18	1.20	3.91	4.73
6	0.14	0.12	0.29	0.07	0.15	0.23	0.09	0.02	0.89	0.49
Background	0.04	0.01	0.07	0.01	0.01	0.02	0.01	0.01	0.02	0.01

[a]OP denotes those wells outside of nitrate-N plume.
[b]Background represents lowest concentration well.
Underlining denotes occupied period.

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