Septic Tank Density and Ground-Water Contamination

by Marylynn V. Yates[a]

ABSTRACT

As more and more cases of ground-water contamination are reported, the public has become increasingly aware of the importance of preserving the quality of this limited resource, especially in areas totally dependent on ground-water sources. Although most of the attention is focused on pollution by organic chemicals, these compounds are responsible for a relatively small percentage of ground-water-related disease outbreaks. The majority of water-borne disease outbreaks are caused by bacteria and viruses present in domestic sewage. Septic tanks contribute the largest volume of waste water, 800 billion gallons per year to the subsurface, and are the most frequently reported cause of ground-water contamination associated with disease outbreaks. The U.S. Environmental Protection Agency has designated areas with septic tank densities of greater than 40 systems per mi^2 (1 system per 16 acres) as regions of potential ground-water contamination. Numerous cases of ground-water contamination have been reported in areas of high septic tank density; lot sizes in these areas range from less than one-quarter acre to three acres. The single most important means of limiting ground-water contamination by septic tanks is to restrict the density of these systems in an area.

INTRODUCTION

Ground-water supplies over 100 million Americans with their drinking water. In rural areas, there is an even greater dependence on ground water, as 90 to 95% of the drinking water used is ground water (Bitton and Gerba, 1984). The increasing dependence on ground water as a source of potable water has spurred efforts to protect the quality of this limited resource.

Septic tank leachate is the most frequently reported cause of ground-water contamination. In 1970, 29% of the United States' population disposed of their domestic waste through individual onsite disposal systems (U.S. Environmental Protection Agency, 1977). This represents approximately 19.5 million single units, almost 17 million of which are septic tanks or cesspools. While the relative percentage of new homes using septic tanks has decreased over the past several years, the total number of septic tanks is increasing at a rate of about one-half million per year (Scalf, Dunlap, and Kreissl, 1977).

It has been estimated that the total volume of waste disposed of via septic tanks is approximately 800 billion gallons per year, virtually all of which is disposed in the subsurface (U.S. Environmental Protection Agency, 1977). This makes septic tanks the leading contributor to the total volume of waste water discharged directly to ground water.

The consumption of untreated or inadequately treated ground water was responsible for over one-half of all the waterborne outbreaks and 45% of all cases of waterborne disease in the United States from 1971 to 1979 (Craun, 1984). Over one-half of the outbreaks occurred in noncommunity systems, 96% of which use ground water, although more cases of illness resulted from outbreaks in community systems (systems that serve at least 15 service connections used by year-round

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[a] R. S. Kerr Environmental Research Laboratory, P.O. Box 1198, Ada, Oklahoma 74820.

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Table 1. Etiology of Waterborne Disease in the United States, 1971-1979 (Craun, 1984)

Disease	*Outbreaks (%)*
Acute gastrointestinal illness	55
Chemical poisoning	11
Giardiasis	11
Shigellosis	8
Hepatitis A	6
Salmonellosis	3
Viral gastroenteritis	2
Typhoid	2
Toxigenic *E. coli* gastroenteritis	<1
Campylobacter gastroenteritis	<1

residents or that regularly serve at least 25 year-round residents). Outbreaks in individual systems, which depend primarily on ground-water sources, accounted for only 1% of the cases of illness. This may not accurately reflect the actual number which occur, as outbreaks in individual systems are usually not recognized or reported.

Etiologic agents were determined in 45% of the outbreaks (Table 1). Only 11% were caused by toxic chemicals; the vast majority were caused by pathogenic (disease-causing) microorganisms. The remainder were classified as acute gastrointestinal illness of unknown etiology. It is believed that many of these were caused by viruses such as the Norwalk virus or rotaviruses (Gerba, 1983), for which detection methods have only recently become available.

Overflow or seepage of sewage from septic tanks or cesspools was responsible for 43% of the outbreaks and 63% of the cases of illness caused by the use of untreated, contaminated ground water. Thus, septic tanks represent a significant threat not only to preserving the potability of ground water, but also to human health.

SEPTIC TANKS AND WATERBORNE DISEASE

There have been several waterborne disease outbreaks attributable to the contamination of ground water with septic tank effluent. Approximately 1,200 people in a town of 6,500 developed acute gastroenteritis, probably due to *Shigella sonnei*, in a two-month period (Craun, 1981). An epidemiological study showed that illness was associated with the consumption of tap water. Further investigation revealed that one of the community's two wells had high levels of fecal coliform bacteria (indicators of fecal pollution by warm-blooded animals). The source of contamination was found, using a dye tracer, to be a church septic tank located approximately 150 ft from the well. A breakdown in the city's chlorinator had resulted in the distribution of 1 million gallons of contaminated water to the community, causing the large outbreak.

An outbreak of 98 cases of hepatitis A (infectious hepatitis) in Arkansas was traced to the use of commercial pellet ice (Craun, 1979). The water used to make the ice, as well as the ice itself, was found to be heavily contaminated with fecal coliform bacteria. A dye study traced the contamination to a septic tank leach field serving a home occupied by persons who had recently had infectious hepatitis.

Another outbreak of hepatitis A resulted from the contamination of an 11- to 180-ft deep limestone formation overlain by 3 ft of glacial till (Vogt, 1961). Well depths ranged from 30 to 100 feet, and most wells were cased through the glacial till and a short distance into the rock. The drinking water well of the first reported case was located 6 ft from the septic tank. Two other wells were located 10 ft away. Four weeks later, 16 individuals from the three households served by these wells became ill within a three-day period. The outbreak was preceded by a period of snowmelt and heavy rainfall, suggesting that virus-contaminated effluent was carried to the drinking water aquifer.

In 1972, five cases of typhoid occurred in a residential area in Washington (Craun, 1979). An epidemiological investigation revealed that a typhoid carrier lived in the area. When a dye was flushed through the septic system of his home, it was detected 36 hours later in several wells in the area, including the ill family's well, which was located 210 ft away. *Salmonella typhi*, the causative agent of typhoid, was isolated from this well water.

A Norwalk-like agent was responsible for over 400 cases of gastroenteritis at a resort camp in Colorado (Craun, 1984). Over one-half of the persons visiting the camp developed diarrhea at the camp or within one week of leaving it. It was found (using dye tracers) that the camp tap water was contaminated with effluent from a septic tank located 50 ft above the spring supplying the camp.

An echovirus was isolated from a 40-ft deep well during an outbreak of gastrointestinal illness in Florida (Wellings *et al.*, 1977). The well was located 100 ft from a solid waste field in the middle of an area bordered by septic tanks. The virus was isolated from sewage, well water, and stools of individuals living in the camp. In addition, six weeks later, an outbreak of 15 cases of hepatitis A occurred in the same camp.

SEPTIC TANK DENSITY

As stated earlier, septic tanks are the largest contributors of waste water to the subsurface. Several features of septic tank systems can contribute to their potential to contaminate ground water. These include: improper construction, siting, installation, and maintenance of the septic tank; depth to water; climate; and geology of the site. However, the most important factor influencing ground-water contamination from onsite waste disposal systems is the density of systems in an area (U.S. Environmental Protection Agency, 1977). Using data obtained from the 1970 Census of Housing, the density of onsite waste disposal systems was mapped on a county-by-county basis. Three density ranges were identified: low (less than 10/mi^2), intermediate (10 to 40/mi^2), and high (greater than 40/mi^2). The U.S. Environmental Protection Agency (1977) has designated areas with a septic tank density of greater than 40/mi^2 (1 per 16 acres) as regions of potential contamination problems.

Controlling the density of septic tanks is generally done at the local government level, although State governments are becoming more involved in the regulation of septic tank siting. Most States regulate septic tank placement by imposing setbacks, minimum percolation rates, and absorption field sizing restrictions. These may be adequate to protect the ground-water quality in areas with low densities of septic tanks; however, when the density increases, the soil's capacity to purify the septage may be overcome, increasing the potential for ground-water contamination.

There are a few States which have laws regulating septic tank density by prescribing a minimum lot size necessary in order for a septic tank installation permit to be issued. These States are listed in Table 2.

SEPTIC TANK DENSITY AND GROUND-WATER CONTAMINATION

In the past, the generally recognized minimum lot size for septic tank placement in areas not served by municipal sewerage has been about 0.47 acres (Reneau, 1979). This standard has been based on engineering considerations rather than on concern for preserving the quality of the environment (Perkins, 1984). Although data on septic tank density in areas of waterborne disease outbreaks are practically nonexistent, many cases of ground-water contamination have been found in areas of high septic tank density. Following are a few examples.

Colorado

The water quality of three mountain communities in Jefferson County, Colorado which utilize individual onsite waste disposal systems was studied (Hall, 1978). Homes were located on 1.5- to 3-acre lots underlain by fractured crystalline

Table 2. Minimum Lot Size Requirements for Septic Tanks

State	*Lot size (acres)*	*Comments*
Alabama (Pate, 1977)	0.34	
Maine (Toppan, 1977)	0.46	
Minnesota (Lee, 1980)	0.46 - 1.84	Only on lakefront property.
Mississippi (State statute 41-67-7)	0.40 0.46	If public water supply. If private water supply. Well must be at least 50 ft from the tank and 100 ft from the disposal field.
Montana (Commission, 1974)	0.23 0.46	No well on property. Well on property.
Nevada (State statute 444.650)	0.25 1.00	If public water supply. If private water supply.
Washington (Plews, 1977)	0.29	Subdivisions or multiple housing units.

rock aquifers. Water samples were collected from 30 wells and analyzed for several pollution indicators. Elevated nitrate levels were found, as were total and fecal coliforms. Ford *et al.* (1980) found that increased nitrate concentrations (over 45 mg/l) in the ground water were associated with increased housing density (more than one residence per acre) in unsewered areas of this same county.

Delaware

Two areas were chosen to study the problem of ground-water contamination by septic tanks (Miller, 1972). The first area was one mile square, with homes on one-quarter to one-half-acre lots. Each home had a septic tank and a shallow well (13 to 35 ft deep). The area was selected because of the high water table, poorly-drained soils, and reports of overflowing septic tanks during rainy periods. The second area was chosen as a result of reports of high (greater than 45 mg/l) nitrate levels in the drinking water. This area was 0.75 mi^2, had deeper wells (35 to 70 ft), and well-drained soils. Houses were on one-quarter to one-half-acre lots.

The results of the study in the first area showed that nitrate levels averaged 6.9 to 11 mg/l, and coliforms were detected in the wells. Nitrate levels in the second area ranged from 22 to 136 mg/l, with many of the wells exceeding the drinking water standard of 45 mg/l. Low-nitrate levels in the water in the first area could have been due to the fact that anaerobic conditions existed which would inhibit nitrogenous compounds such as ammonia and urea from being oxidized to nitrate.

One conclusion reached by Miller was that percolation tests are not necessarily the best means of determining the suitability of a site for a septic tank system, especially if performed during the dry season. Another recommendation was that, to decrease the potential for ground-water contamination, the regulation allowing two 4-bedroom homes to occupy a one-acre lot be changed to allow one 4-bedroom home per two-acre lot.

Massachusetts

The U.S. Geological Survey conducted a study of ground-water quality in 17 small (less than 1 mi^2) drainage basins of the Ipswich and Shawsheen Rivers in a suburban area north of Boston (Morrill and Toler, 1973). The areas were all served by public water supplies, but none had municipal sewers. Housing density ranged from 0 to 900 units per mi^2. Chloride and specific conductance were used as indicators of contamination by domestic sewage. The concentration of chloride in the septic tank effluent was 50 ppm higher than in the public water supply. The investigators showed a correlation between the relationship of housing density to residual conductance, and the accretion of dissolved solids in the baseflow of streams.

New Mexico

Extensive pollution of drinking water wells has resulted from septic tank effluent in the middle Rio Grande Basin (Wright, 1975). It was estimated that there are over 16,000 septic tanks in a 30-mile stretch of the river. Due to the sandy and gravelly nature of the soil, the effluent is not adequately purified before it reaches the relatively shallow aquifer, thereby contaminating the drinking water.

New York

Ground-water contamination has been demonstrated in Nassau County, Long Island, which has over 100,000 septic tank systems (Miller, Deluca, and Tessier, 1974). Nitrates, mainly from septic tanks and fertilizers, have penetrated hundreds of feet into an artesian aquifer. Several public water supply wells were found to have nitrate levels exceeding the drinking water standard of 45 mg/l. A survey of the streams in the area revealed that ground-water-fed streams averaged 11 mg/l nitrate in sewered areas and 25 mg/l in unsewered areas, suggesting that septic tanks are a significant contributor to the problem of nitrate contamination of the ground water.

North Carolina

Elevated nitrate and chloride concentrations were found in the well water of several subdivisions using septic tank systems in Raleigh, North Carolina (Miller, Hackenberry, and DeLuca, 1977). Most of the homes were on lots ranging from one-quarter to over one-half acre in size. The wells were 100 to 200 ft deep, and drilled into fractured granites, schists, and gneisses. Although nitrate levels were not above standards, the increase in concentration above background was confirmed to be caused by septic tank contamination.

DEVELOPING REGULATIONS TO CONTROL SEPTIC TANK DENSITY

As the importance of safeguarding the quality of the nation's water supply has become widely recognized, standards regarding septic tank placement are being changed. According to the Farmer's Home Administration, many counties and States are increasingly providing rural zoning ordinances or laws that limit the use of septic tanks to 2- to 10-acre lots (Rose, 1978).

Several approaches can be taken in developing regulations regarding septic tank density with the goal of preserving ground-water quality. One of these is to impose minimum lot size requirements larger than those which have been found to be associated with ground-water contamination. Another is to evaluate each potential site individually, taking into consideration the geologic characteristics of the site and methods of waste disposal being practiced in the surrounding area. A third approach would be to calculate the amount of dilution of the effluent that is required before it reached the ground water to minimize the pollution potential. For example, based on measured nitrate concentrations of the septic tank effluent in an area of eastern Connecticut, it was calculated that the effluent would have to be diluted at least one to one before reaching the water table to reduce nitrate concentrations to the drinking water standard of 45 mg/l in permeable soils with deep water tables (Holzer, 1975). It was calculated that the density would have to be limited to one residence per acre on well-drained sites in areas covered by till to achieve the desired dilution.

Several mathematical models have been developed which can be used to predict the extent of ground-water contamination; these have been reviewed by Perkins (1984). These models allow input of specific local characteristics such as the hydraulic conductivity of the aquifer, rainfall, and evaporation. Using the drinking water standard for the desired contaminant, the lot size required to meet that standard is then computed.

While these models can provide useful information, it must be kept in mind that in any mathematical model, assumptions are made which may not be valid for every individual case. In addition, most models of contaminant movement are valid only for chemical substances such as nitrate and chloride.

Very few models exist on the movement of bacteria and viruses in the subsurface, although they are the major causes of waterborne disease in the United States. There have been a few studies which have actually followed the movement of bacteria and viruses from septic tanks to ground water. From the results of these studies, summarized in Table 3, it is apparent that pathogenic microorganisms in domestic waste water can survive in septic tanks, migrate through the leach field, and reach ground water.

Table 3. Virus Movement from Septic Tanks

Site	*Virus detection*
New Mexico	11 ft from source in 15 ft-deep well (Hain and O'Brien, 1979).
New York	213 ft from source in sandy soil (Vaughn *et al.*, 1983).
Texas	82 ft from source in well (Wang *et al.*, 1981).
Wisconsin	175 ft from source 12 days after introduction into septic tank (Stramer, 1984).
Wisconsin	In wells up to 131 days after introduction into septic tank (Stramer, 1984).

Recently, information regarding the factors which control the length of time viruses can survive in ground water has been obtained (Yates, 1984). These data, along with hydrogeologic information such as hydraulic conductivity, porosity, and hydraulic gradient, will be used in a model to predict virus movement in the subsurface. The model can then be used to predict safe distances between drinking water wells and sources of contamination such as septic tanks.

CONCLUSIONS

1. Septic tanks are the major contributors of waste water to the subsurface.

2. Over one-half of the waterborne disease outbreaks in the United States are due to the consumption of contaminated ground water; septic tanks are the most frequently reported cause of contamination.

3. The most important factor influencing ground-water contamination by septic tanks is the density of systems in an area.

4. Several cases of ground-water contamination have been reported in areas of high septic tank densities; lot sizes in these areas range from less than one-quarter to three acres.

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Marylynn V. Yates received her Ph.D. in Microbiology from the University of Arizona. She also has an M.S. in Chemistry from New Mexico Institute of Mining and Technology, and a B.S. in nursing from the University of Wisconsin-Madison. Currently, she is a postdoctoral research associate in the Departments of Microbiology and Immunology and Chemistry at the University of Arizona, Tucson, Arizona.

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