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The Great Phosphate Debate:

Does Detergent Formula Affect Groundwater Contamination?

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Protection of groundwater is important to Wisconsin for two reasons: *people depend heavily on groundwater for drinking water and polluted water may cause public health hazards* and *nutrient-bearing groundwater discharging to surface water can contribute to eutrophication of recreational lakes and streams that are important to the tourism economy.* This document summarizes a doctoral thesis by B. J. Alhajjar (1985) at the University of Wisconsin-Madison.

Trends favor establishing permanent residential development around highly desirable lakeshores in rural areas. Present policies on public sewer extensions favor relying on septic systems as a permanent means of wastewater disposal in outlying areas. Wisconsin has more than 600,000 septic systems, with many in sandy soils where the biochemical and physical purification processes of household wastewater may be insufficient. Septic tank effluent not sufficiently purified during soil percolation may pollute groundwater with phosphorus (P), nitrogen (N), bacteria, and viruses.

A ban on P in detergents in Wisconsin (Chapter 375 W.S., 1977) provoked concern for the effects that P-free, carbonate (CO_3)-built detergent might have on the performance of septic systems. Such concerns justified initiating an investigation of the effects which P-built and P-free detergent formulations have on the performance and treatment efficiency of septic systems and on the quality of groundwater under coarse-textured soils close to discharge areas. A particular focus was on the potential movement of N, P, bacteria, and viruses into the groundwater from septic systems. Two groups of septic systems were studied. The first comprised eight systems receiving wastes from households using P-built laundry detergent. Nine systems in the second group received wastes from households using P-free, CO_3-built detergent. All were new or replacement systems of approximately the same age, located in sandy soils over shallow aquifers close to groundwater discharge areas in south-central Wisconsin (Fig. 1). Each homeowner was given a supply of P-built or P-free detergent for the study and requested to keep records of the load size and frequency of laundry, and the nature and frequency of use of laundry additives (bleaches, fabric softeners, etc.).

The direction of local groundwater flow at each site was determined using a "Dowser" model 10 groundwater flow meter (K-V Associates, Falmouth, Mass.). Three wells were placed in the effluent plume downflow from the drainfields of individual septic systems. Groundwater monitoring wells labeled No. 1 were 30 cm from the edge of the drainfield and Nos. 2 and 3 were downflow at intervals of 3 m. Background (control) monitoring wells labeled No. 4 were more than 10 m from the edge of the drainfields upflow in the hydrologic gradient at each site. Additionally, wells labeled No. 5 were installed immediately adjacent at the drainfield at sites 8 (a P system) and 10 (a CO_3 system).

All wells extended to a depth of 1 m below the water table and were sealed to prevent intrusion of surface water. The soil removed from drill holes was placed in sequence on a clean sheet of plastic and the soil profile was described. Water meters were installed at each household and water loads to individual septic systems were determined.

Depth to the water table from the land surface was measured for each well just before pumping to determine the seasonal fluctuation of water table in the vicinity of the systems.

Each month for two years, samples of effluent from each septic tank and water from wells in the vicinity of each system were collected in clean plastic bottles and kept on ice

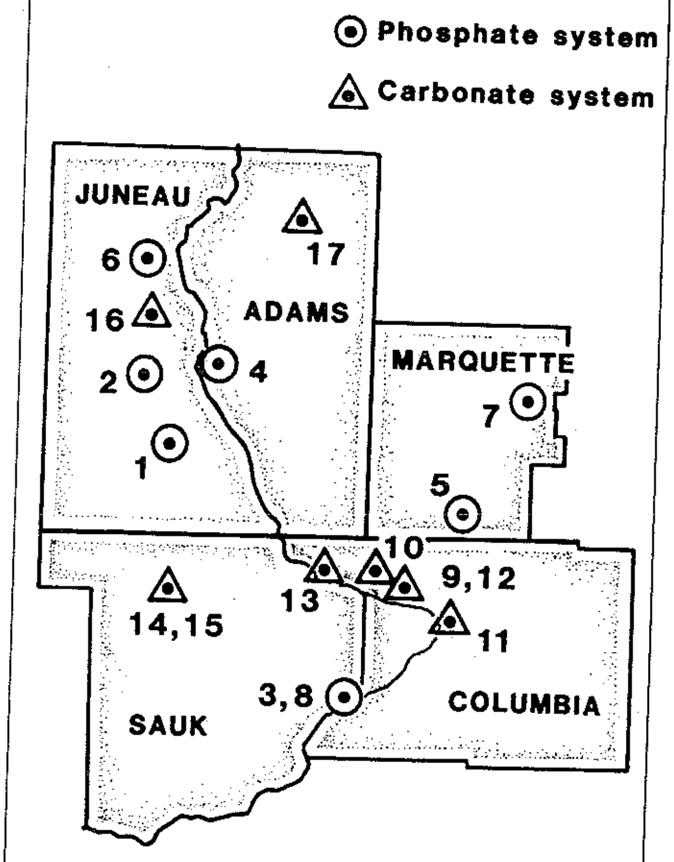

Figure 1. Locations of septic systems.

during transport to the laboratory where they were refrigerated at 4°C. Samples for bacterial and viral analyses were collected in sterilized bottles. Temperature and pH were measured on effluent and water samples *in situ*.

The septic system at site 8 was inoculated with a total poliovirus dose of 3.3 x 10^{10} count/100 ml by flushing down the toilet. The inoculum was obtained from stools containing various combinations of the three polio virus serotypes in diapers of infants who received the Sabin trivalent oral poliovirus vaccine. Over a period of six months, effluent and groundwater samples were collected for virus analysis from the septic tank and the monitoring wells. Data for the virus study were collected by Stramer (1984).

At the end of the study, soil samples at the gravel-soil interface (the site at which a clogging mat forms naturally in septic systems) were collected at each system and a total carbon analysis was made. A followup was conducted by a last round of sampling at all sites after approximately five years of system operation.

Laboratory analysis

Total coliforms (TC), fecal coliforms (FC), and fecal streptococci (FS)—used as indicators for the presence of pathogenic bacteria—and poliovirus (PV) were assayed at the Food Research Institute, UW-Madison; assays were begun within twelve hours of sampling. Chemical analyses were conducted at the Soil Science Department, UW-Madison. Chloride (Cl), electrical conductivity (EC), sodium (Na), nitrate (NO_3), ammonium (NH_4), total N, ortho-P (soluble), and total P were determined on effluent and groundwater samples. Potassium (K), calcium (Ca), magnesium (Mg), biochemical oxygen demand (BOD), solids (total, total volatile, total suspended, and volatile suspended), alkalinity, and indicator bacteria were determined on effluent samples. Indicator bacteria were counted regularly in water samples from the wells near septic system Site 8 and occasionally in others. Fluorescence was determined on water samples; turbidity interfered with measurements in septic tank effluent.

Data were examined thoroughly, statistically evaluated, and modeled at individual sites by applying techniques that are either discriminatory or not to outliers. The data were pooled at individual effluent and groundwater sampling locations based on detergent type for sites 1 to 8, 9 to 17, and all sites. The resulting pooled populations were statistically evaluated. The Cl concentrations were used as tracers to estimate amount of undiluted effluent in the plume of pollution at wells 1, 2, 3 and 5. Monte Carlo (stochastic) simulations were used to account for various sources of uncertainties on estimates of contaminant transport to groundwater or contaminant removal in the soil. Association of a simple contaminant transport model with stochastic simulation properly described the transport of effluent P, N, TC, FC, and FS but not PV groundwater. The combined model provided applicability to a large area, accountability for variations in data and greater power of prediction. Simulations were sound by statistical evaluation and the conclusions that resulted from other statistical techniques were comparable to the simulated results.

Linear multiple regression models were used to investigate which effluent characteristics were important in predicting quality of effluent from septic systems as a function of detergent type.

Statistical analysis and stochastic transport modeling of the large two-year data base from the two groups of septic systems receiving detergents of two types led to the following conclusions:

1. Drawing general conclusions from a single constituent could yield misleading information about the nature and distribution of other groundwater contaminants. In particular, conclusions drawn on the nature of P and N from Cl, EC, or fluorescence are usually misleading.

2. Based on median values, all septic systems under investigation were seeping NO_3 to the local groundwater and 12 of 17 systems in excess of the drinking water standard of 10 mg/liter as NO_3-N.

3. Significant local groundwater contamination by NH_4 (median of greater than 1 mg/liter as N) was detected in 5 of 17 systems in the immediate vicinity of the absorption fields. However, only one system remained high in NH_4 at a distance of 6 m from the drainfield.

4. Soils at individual septic systems were extremely efficient in removing P from effluents regardless of their coarse texture. Even after receiving septic tank effluent leachate, groundwater at all sites contained a median of <0.1 mg/liter of total P, the level EPA recommended to control eutrophication at points where waters are not discharging directly to lakes and streams.

5. Results from the simulation transport of effluent—inferred from Cl concentrations—for N and P are found in Table I.

Table I. Summary Percentages from the Monte Carlo simulation of the amount of effluent, total nitrogen transported (NT), and total phosphorus transported (PT) to the intercepted groundwater plume from septic systems receiving laundry wastes of P-Built and CO_3-built detergents, and all systems combined

	No. of samples	mean	90% confidence interval
P-Built Detergents			
Amount of effluent (%)[1]	595	39	38–40
% NT	595	54	51–57
% PT	595	0.52	0.35–0.70
CO_3-Built Detergents			
Amount of effluent (%)	444	45	35–54
%NT	444	94	92–96
%PT	444	0.05	0.02–0.08
All Systems			
Amount of effluent (%)	1,039	42	36–47
%NT	1,039	71	69–72
%PT	1,039	0.32	0.26–0.39

[1]Inferred from Cl concentrations.

Table II. Summary Percentages from the Monte Carlo simulation of the amount of effluent, total coliform transported (TCT), fecal coliforms transported (FCT), and fecal streptococci transported (FST) to the groundwater plume intercepted at site 8

	No. of Samples	Mean	90% confidence interval
Amount of Effluent (%)[1]	600	19	16–21
% TCT	600	1.0	0.8–2.0
% FCT	600	0.2	0.12–0.23
% FST	600	0.2	0.17–0.21

[1]Inferred from Cl concentrations.

The P transported (percent PT) to the monitoring wells did not exceed a mean of 1 percent (a mean of <0.1 mg/liter) for both groups of sites. **Therefore, neither detergent type contributes to groundwater contamination by P, and properly functioning septic systems are not a source of P to groundwater, are not a biological nuisance, and do not contribute to lake eutrophication.** Conversely, the mean level of N transported to groundwater (percent NT) is 54 and 94 percent respectively from septic systems receiving laundry wastewater of P- and CO_3-built detergents. This corresponds to 39 and 69 mg/liter of N reaching groundwater from septic systems processing P- and CO_3-built detergents. This means that the systems leached an average of four and seven times more N to local groundwater than the recommended standard of 10 mg/liter with P- and CO_3-built detergent use. The use of P-built detergents reduces N transport to groundwater by approximately 57 percent.

6. Although banning of P from laundry detergents reduces the P load reaching sewage treatment plants in sewered areas, thereby reducing the cost for tertiary treatment for P removal and for sludge disposal on land, it is not recommended in unsewered areas where septic systems are in use and groundwater contamination by N is more critical. Unsewered areas should not be included and affected by the P ban in laundry detergents, as recommended by the Wisconsin Center for Public Policy (1984). A P detergent ban does not have to be statewide: regional and/or municipal bans could be implemented. The current P ban on laundry detergents in Wisconsin, however, does have some environmental benefits. Only 55 of Wisconsin's 600 sewage treatment plants have P removal capacity sufficient to reach the purification standard of 1 mg/liter P. Until the rest of the treatment plants are upgraded, the P ban serves as an interim measure for improving water quality of the state's lakes and waterways and the Great Lakes. On the other hand, the ban places some economic burdens on the consumer due to higher detergent use for P-free formulations. Our results showed that households receiving CO_3-built detergent laundered slightly more frequently and used considerably more detergent than households using P-built detergent (average of 76 and 66 loads/year/capita, and 20 and 12 g detergent/day/capita).

7. Results of simulated transport analysis of effluent—from chloride data—for TC, FC, FS, and PV are presented in Table II. Indicator bacteria were not transported to local groundwater but were completely removed by the soil under the seepage bed. The means of numbers of TC, FC, and FS transported were >1 count/100 ml of groundwater, in keeping with the U.S. Public Health Service drinking water standard. On the other hand, the inoculated PV managed to escape from the system in the effluent entering the soil under the seepage bed. Of the 3.3 x 100^{10} counts/100 ml of poliovirus inoculated into the septic tank, a mean of 70 counts/100 ml escaped from the tank with the effluent and an overall mean of 62 counts/100 ml was transported to groundwater (88 percent transport).

8. An extremely important observation was the greater likelihood that viruses are encountered in water from wells at a greater distance from the septic tank system than those close to it. This corresponded with the higher ionic strength closer to the septic systems. Viruses appear to be adsorbed to the sediments of the unconfined aquifer closer to the septic system due to high ionic strength, and to desorb farther away from the drainfield as a result of reduction in ionic strength. Ionic strength of groundwater from well 5 was four times higher than that of water from other wells.

9. Indicator bacteria (TC, FC, and FS) cannot be used as indicators for the presence of viruses; the soil retained the indicator bacteria but not the much smaller virus. Virus contamination of groundwater through septic tank leachate resulted from what was otherwise a well-functioning conventional system. The system was new and had no clogging layer when the tests were conducted. An older system with a mature clogging mat might not leak as many viruses.

10. Results of multiple regression analyses also indicated improved retention of NH_4 with the use of P-built detergent. This may be due to precipitation in the septic tank of $MgNH_4PO_4$ and/or nitrification followed by denitrification in the soil. However, effluent quality was better with the CO_3-built detergent and groundwater pollution by other chemical species based on Cl data was higher with P-built detergent. This must be because Na tripolyphosphate in the P-built detergent is a complexing agent for cations, whereas Na_2CO_3 in the P-free detergent is a precipitating agent for Ca and Mg. These cations attract such anions as Cl, and Na, K, Mg, and Ca as well as Cl concentrations were significantly higher in effluents from systems receiving P-built detergents. For the same reason, EC, alkalinity, filtered and unfiltered total solids, total volatile solids, total suspended solids, volatile suspended solids, temperature, Na adsorption ratio, and BOD were higher in systems receiving P-based detergents. With its higher nutrient and energy content this effluent may stimulate growth of denitrifying bacteria, thus enhancing N loss to the atmosphere and significantly reducing groundwater contamination by N. The amount of carbon—an energy source for bacteria—in the clogging mat was on average four times higher with P-built than CO_3-built detergent.

11. Multiple regression analyses showed the effect of CO_3-built detergent was to increase buffer capacity of effluents thereby preventing the drastic pH increase expected. No significant differences in pH were found in the two types of effluents resulting from detergent use.

12. Total counts of indicator bacteria in effluents obtained from households using P-built detergent were approximately 10 percent higher than for those using CO_3-built detergent. This increase in bacterial growth as a result of the excess P from the P-built detergent caused slightly improved treatment and degradation of organic matter.

13. Fluorescence was not a good tracer for detecting plumes of contamination emanating from septic systems. The fluorescence in the water resulted from materials, such as humic or fulvic acids, other than optical brighteners derived from laundry products; optical brighteners generally did not pass undecomposed through the septic system.

14. Shallow groundwater quality in the Wisconsin, Lemonweir, Yellow, and Baraboo river basins of south-central Wisconsin is relatively better than the Fox and Mecan river basins; this may be due to greater human activities in the latter basins.

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