WASHINGTON STATE DEPARTMENT OF HEALTH

Rule Development Committee Issue Research Report - Draft
Type 1A Soil Issues

For information or additional copies of this report contact:
Wastewater Management Program

Physical address: 101 Israel Road SE, Tumwater, WA 98501
Mailing Address: PO Box 47824, Olympia, Washington 98504-7824

Phone: (360) 236-3330
Webpage: www.doh.wa.gov/wastewater
Email: wastewatermgmt@doh.wa.gov

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DOH Staff Researcher(s):	**John Eliasson**
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Topic & Issues:

Type 1 A Soil Issues

- **How are excessively permeable (Type 1A) soils currently described?**
- **What are the treatment concerns in excessively permeable (Type 1A) soils?**
- **Is there a need to make adjustments to our existing description? If so, what changes should be made?**
  - Should the definition of "vertical separation" be clarified in respect to Soil Type 1A?
  - Should changes be made to the coarse fragment fraction of the fine earth (non-gravel) portions?
  - Should changes be made to the fine earth (non-gravel) soil types of extremely gravelly soil?
  - Should 1A & 1B Soils be combined?
- **Is there a need to make adjustments to treatment requirements in excessively permeable (Type 1A) soils? If so, what changes should be made?**

Summary:

This report summarizes the literature on the topic of Type 1 Soil issues for on-site sewage systems. Numerous studies have demonstrated that bacteria, viral, and nutrient movement presents a potential problem in excessively permeable soils. The rapid flow of effluent through macropores decreases treatment because of reduced soil surface area and retention time. In this situation, inadequate treatment in the unsaturated zone might allow wastewater contaminants to enter the ground water if no mitigating measures are taken. There is little research that has clearly demonstrated at what point the percent gravel fraction of the native soil results in a treatment problem.

Several studies indicate that conventional gravity systems are ineffective in treating domestic wastewater in coarse textured soils. Research have shown that when hydraulic loading rates are too high or the dosing frequency is too low, wastewater constituents can be transported to lower regions in the soil, posing a treatment concern in systems that are close to ground water. Improved treatment of microbiological and chemical constituents can result from more frequent application of small doses of septic tank effluent that is uniformly applied to coarse textured soils.

Research has shown that in unsaturated coarse textured soils a high degree of biological nitrification can be expected. In such cases, a decline in nitrate concentrations is largely attributed to dilution and dispersion. Several studies indicate that minimal nitrate removal occurs in pressurized systems located over sand or coarser soil. Shallow wells with coarse-grained glacial deposits at the surface are most susceptible to elevated nitrate concentrations because they tend to receive water with short flow paths and these parts of the aquifer system are more likely to have oxic water. In such high-risk settings, system designs should incorporate additional nitrogen removal technologies prior to final soil discharge. Situations that involve rapid phosphorus transport to surface water are reasonably well-understood and generally related to the siting and design of on-site systems and hydrologic settings.

KEYWORDS: *Coarse soils, coarse sand, coarse-textured soil, coarse-grained soil, excessively permeable soil, rapidly permeable soil.*

Introduction:

Domestic wastewater contains several constituents that could cause significant public health or environmental risks if not treated effectively before they are released into the environment. The properties of the soil are one of the most important factors when determining effective design for an on-site sewage system. Soil properties such as those with large pores and high permeability, which characterizes Type 1 Soils, can result in the rapid transport of bacteria, viruses, and nutrients to groundwater, if an improper system design is used.

In Washington State, such soils have often developed on coarse-grained glacial deposits (loose, sand and gravel) by recessional and advance glacial outwash during our last glacial period. These deposits represent some of our most productive and vulnerable drinking water aquifers in the State. Because of the high permeability of these soils, they have the advantage of having good hydraulic performance due to less clogging at their infiltrative surface. However, their high hydraulic loadings can produce rapid-localized preferential flow paths allowing wastewater contaminants to pass through the unsaturated zone into the groundwater untreated.

Currently, Soil Type 1A is described as very gravelly coarse sands or coarser, and all extremely gravelly soils (> 60% gravel and coarse fragments by volume) in WAC 246-272. The gravel portion description for 1A soils was created from the USDA NRCS gravel modifier delineation between very gravelly (35 to <60%) and extremely gravelly (60 to <90%), and is not necessarily based on a demonstration that these soils behave similarly, in respect to wastewater treatment and hydraulic performance. In any event, when Soil Type 1A is encountered enhanced treatment (Treatment Standard 2) is required unless protective site features are demonstrated for permitting conventional gravity systems according to the criteria established in WAC 246-272-11501(2)(h).

The purpose of this review is to synthesize the literature available on the topic of type 1A soils (excessively permeable soil) so that the Technical Review Committee can make appropriate recommendations about this soil description, and system design requirements to address the wastewater constituents of concern. More than 125 publications, which include peer reviewed journal articles, conference proceedings, text books, master thesis, and government reports were collected and reviewed.

Body:

Background

WAC 246-272 recognizes the inadequate treatment performance capabilities of coarse-grained soils due to their rapid permeability, and attempts to account for this condition by describing it according to sand grain size, and the textural (fine earth) gravel content by volume. For soil with increasing gravel content (>60%), their respect hydraulic conductivities are expected to become significantly higher. Prior to the State On-Site Sewage System Regulation revision in 1995, Soil Type 1 was described as "coarse sands or coarser", and included other soils and/or conditions where the treatment potential is ineffective in retaining and/or removing substances of public health significance to underground sources of drinking water. The 1995 regulation revision redefined this description to include "very gravelly, or extremely gravelly soil", which created two distinct classes (1A and 1B) for greater accuracy. The hydraulic loading rate for Soil Type 1A varies according to the system selected to meet Treatment Standard 2. The hydraulic loading rate for Soil type 1B varies according to the rate that is assigned to the non-gravel (fine earth) portion of the native soil by Table V.

WAC-246-272 TABLE V
Maximum Hydraulic Loading Rate
For Residential Sewage[1]

Soil Type	Soil Textural Classification Description	Loading Rate gal./sq. ft./day
1A	Very gravelly[2] coarse sands or coarser, extremely gravelly[3] soils.	Varies according to system selected to meet Treatment Standard 2 [4]
1B	Very gravelly medium sands, very gravelly fine sands, very gravelly very fine sands, very gravelly loamy sands.	Varies according to soil type of the non-gravel portion [5]
2A	Coarse sands (includes the ASTM C-33 sand).	1.2
2B	Medium sands.	1.0
3	Fine sands, loamy coarse sands, loamy medium sands.	0.8
4	Very fine sands, loamy fine sands, loamy very fine sands, sandy loams, loams.	0.6
5	Silt loams that are porous and have well developed structure.	0.45
6	Other silt loams, sandy clay loams, clay loams, silty clay loams.	0.2

[1] Compacted soils, cemented soils, and/or poor soil structure may require a reduction of the loading rate or make the soil unsuitable for conventional OSS systems.

[2] Very Gravelly = >35% and <60% gravel and coarse fragments, by volume.

[3] Extremely Gravelly = >60% gravel and coarse fragments, by volume.

[4] Due to the highly permeable nature of type 1A soil, only alternative systems which meet or exceed Treatment Standard 2 can be installed. However, a conventional gravity system may be used if it meets all criteria listed under (h) of this subsection (WAC 246-272-11501(2)(h). The loading rate for these systems is provided in the appropriate guideline.

[5] The maximum loading rate listed for the soil described as the non-gravel portion is to be used for calculating the absorption surface area required. The value is to be determined from this table.

Systems installed in Soil Type 1B with less than 3 feet of vertical separation, as a minimum, must use pressure distribution. Those installed in Soil Type 1A must be alternative systems capable of meeting Treatment Standard 2 (<10 mg/l BOD5, <10 mg/l total suspended solids, and <800 fecal coliform per 100 ml). A specific exemption to this requirement permits a conventional gravity system to be used on a site if it is located in Eastern Washington and meets site constraints and requirements in the "Design Guideline for Conventional Gravity Distribution On-site Sewage Systems in Soil Type 1A (See WAC 246-272-11501(2)h).

Excessively Permeable Soils (Soil Type 1A)

There is little research that has clearly demonstrated hydraulic and treatment performance in native soil with high coarse fragments (gravel content) greater than 60 percent by volume. In a study on the disposal of household wastewater in soil of high rock content (silt loam with 35-50% coarse fragment by volume), Rutledge et al. (1983) found that saturated hydraulic conductivity rates, not the rock contents of the soil horizons, are important in predicting on-site sewage system performance. Recently, Bates (1998) conducted a laboratory column study comparing the saturated hydraulic conductivities of six soils types (types 2A-6) with Soil Type 1A in Benton and Franklin Counties of Washington. The author found that the hydraulic conductivities of extremely gravelly soils (61-65% coarse fragment by volume) are not similar and are influenced by the intergravel soil constituents rather than the gravel content. Based on the different hydraulic conductivities of the extremely gravel soils (Type 1A), the author suggested that it may be more appropriate that these soils be treated in a similar fashion as to the very gravelly soil classification (Type 1B), in which the classification of extremely gravelly soil would be based on the characteristics of their corresponding fine earth (non-gravel) portion. Soils with higher amounts of gravel than used in these studies (>65% coarse fragment by volume) are likely to be more hydraulically influenced by the gravel content. The exact percent gravel content at which treatment becomes at problem in native soil, however, is still not well understood (Cogger, personal communication, 2002).

In an attempt to provide additional information on the description of rapidly permeable soils (Soil Type 1A) and corresponding system siting/design requirements, a review other of states rules was conducted. Table 1 summarizes the findings of this review. Of the states reviewed, there appears to be general agreement that the permeability is high enough in very coarse sand or coarser, extremely gravelly sands (loamy, fine, medium, and coarse) and all soil with at least 90% coarse fragments (gravel, cobbles, stones, and boulders) to require enhanced treatment in lieu of relying on these soils to treat septic tank effluent.

Table 1.

State	Characterization of Rapidly Permeable Soils (Soil Type 1A)	On-Site Requirements
Colorado	Gravel (>5 minutes/inch percolation rate)	Design by registered Professional Engineer required.
Delaware	Rock with open joints, fractures or solution channels, masses of loose rock fragments, or loose weathered rock, including gravel, with insufficient fine soil to fill the voids between the fragments.	3 feet of vertical separation required.

Florida	Coarse Sand with an estimated wet season high water table within 48 inches of the bottom of the proposed drainfield; Gravel or Fractured Rock or Oolitic Limestone.	Unsatisfactory for standard subsurface system. Site can be approved provided a minimum depth of 42 inches of rapidly percolating soil is replaced with coarse sand or finer sand and the drainfield is sized using a maximum loading rate of 0.8 gpd/ft^2 for trenches or 0.70 gpd/ft^2 for beds.
Idaho	Gravel (10 Mesh**)**	Unsuitable. Depending on soil texture, 3-6 feet vertical separation required.
Kansas	Gravelly coarse sand and coarser	Not recommended for conventional soil absorption system. Use pressure distribution dosing or other alternative to prevent rapid infiltration.
Minnesota	Coarse sand (faster than 0.1 minute/inch percolation rate.	Mound system required or a trench system with at least 1 ft of clean sand placed between the distribution medium and the coarse soil along the excavation bottom and sidewalls.
Missouri	Soil greater than 50% rock fragments and there are severe geological limitations.	Sand-lined trenches required.
New Jersey	"Excessively coarse horizon or substrata. Soil horizons or substrata which have a coarse fragment contain greater than 50% by volume shall be considered excessively coarse regardless of their measured permeability or percolation rate. Sand textured soil horizon or substrata which contain less than 50% by volume coarse fragments shall be considered excessively coarse if they are composed primarily of coarse-very coarse sand (from 0.5 to two millimeters in diameter) and lack detectable amounts of (≥2%) of silt and clay. Soils which lack detectable amounts of silt and clays are soils which are dominantly gritty to the touch, lack cohesion when moist, lack stickiness when wet and do not stain the fingered when subbed in the hand.	Minimum 4 ft. vertical separation required for treatment and an addition 4 ft. vertical separation required for disposal. Sand-lined bed or mound system allowed in excessively coarse horizon or substrata.
Ohio	Soil such as coarse sands known to provide inadequate treatment within the vertical separation distance.	Pretreatment for pathogen reduction and nutrient reduction as needed.

Oregon	"Soil With Rapid or Very rapid Permeability" means (a) Soil which contains 35% or more coarse fragments 2 millimeters in diameter or larger by volume with interstitial soil of sandy loam texture or coarser, or (b) coarse textured soil (loamy sand or sand), or (c) stones, cobbles, gravel, and rock fragments with too little soil material to fill interstices larger than 1 millimeter in diameter.	A minimum of 18 inches of vertical separation must be maintained.
Washington	Very gravelly coarse sands or coarser, extremely gravelly soils	2-3 feet vertical separation required. System meeting Treatment Standard 2.
Wisconsin	Very coarse sand or coarser.	10 ft. of unsaturated soil required with $>10^4$ cfu/100ml effluent quality or 5 ft. of unsaturated soil required with $\leq 10^4$ cfu/100ml effluent quality.

Bacterial Removal

Bacteria are removed largely by filtration, that is, they are trapped in soil as the water passes through the soil matrix. Therefore, bacteria are removed to a greater degree in soils with small pores than in coarser-textured soils such as sands and gravels (Cantor and Knox, 1985). Tare and Bokil (1982) examined the effect of various particle size distributions on removal of bacteria in columns from 3 to 30 inches in length. Sand, silt, and clay particles were mixed at various ratios from 0 to 100% sand. Bacterial removal was greater in mixtures with higher percentages of clay and silt particles. The authors concluded that a mixture of 40% < 75um and 60% > 75 um soil particles was the most efficient mixture for attenuation of bacteria.

As part of a study of bacteria transport in coarse-grained soil, Peterson and Ward (1987, 1989) developed a bacterial transport model in coarse-grained soils to determine whether 4 feet of soil depth was adequate for removing fecal coliform bacteria during high rainfall events. Their results suggest that enteric bacteria are likely to move more than 4 feet from the point of application in coarse-grained soils. Results also suggested that amount of fines and organic matter content are major factors leading to bacterial retention.

Bacteria, which have many nutritional requirements, usually die off once filtered from the effluent. Survival times of enteric bacteria in the soil are generally reduced by higher temperatures, lower nutrient and organic matter content, acidic conditions, lower moisture conditions, and the presence of indigenous soil microflora (Cantor and Knox, 1985). Parker and Mee (1982) studied the survival of *Salmonella adlaide* and fecal coliforms in two coarse sands influenced by two sources of septic tank effluent. *Salmonella adlaide* and fecal coliforms showed similar survival rates for one soil but not another. Average survival of 10% of fecal coliforms was 64 days, with 46 days for equivalent survival of Salmonella. The authors found that survival for fecal coliforms and *Salmonella Adelaide* was less at saturated conditions than at 5% moisture content. However, analyses of variance showed that moisture content differences overall had no significant effect on survival. The authors concluded that survival times for bacteria could not be predicted by soil moisture content.

The bacterial contamination of the groundwater by the disposal of septic tank effluent into rapidly permeable soil have been documented by many researchers (Schaub and Sorber, 1977; Sinton, 1986; DeWalle and Schaff, 1980); McGinnis and De Walle,1983); Ver Hey and Woessner, 1987). Several investigators found that bacteria declined rapidly when transported through dispersed sediments indicating that bacterial pollution occurs primarily by transport of water through macropores (Abu-Ashour et al., 1998; Howell et al., 1996).

McGinnis and DeWalle (1983) reported on the movement of typhoid organisms in saturated soils leading to an outbreak of typhoid fever in Yakima, Washington. The drinking water was contaminated from a gravity flow on-site system located 210 feet up-gradient from the groundwater well. The system was located in an Ashue soil series with an extremely gravelly sand substratum and a water table within 7 feet of the soil surface. Dye added to the septic tank reach the groundwater well within 36 hours.

Ver Hey and Woessner (1987) examined movement of bacteria from gravity flow on-site sewage systems placed in coarse textured alluvial soils (extremely cobbly sand) in Montana. Bacteria were found in samples collected just above the water table at depths of 8 ft and 14 ft below the surface indicating little filtration of bacteria was occurring. The authors concluded that the unsaturated zone does not supply appreciable treatment to septic tank effluent due to its large interstitial pore spaces and minimal number of exchange sites.

DeWalle and Schaff (1980) examined well records and water samples over a 30-year period in a densely populated area of Central Pierce County. The population of the area was 242,000 with 100,000 of the residents on on-site systems. Coarse-grain glacial deposits underlaid the study area. The wells depths ranged from 201 to 1,064 feet. As many as 35% of the wells that were located in areas served primarily by on-site systems were contaminated with total coliforms. Increases in values for nitrate, chloride, and specific conductance were observed and attributed to the presence of sewage effluent from on-site sewage systems, since the deteriorating groundwater quality was most noticeable in unsewered areas. Winter months produced the highest coliform and nitrate concentrations, which were attributed to infiltrating rainfall dissolving and leaching the contaminants downward.

Other investigators using coarse soils have had similar results. Schaub and Sorber (1977) examined the movement of bacteria after wastewater was applied to rapid infiltration basins in Massachusetts. Most bacteria were in the coarse textured sediments. Fecal streptococci, however, were found in the groundwater 95 feet below the soil surface. The effects of two methods of septic tank effluent disposal on the microbial quality in glacial outwash gravels was investigated by Sinton (1986) at an experimental site in the Canterbury Plains, New Zealand. The movement of bacteria 29.5 feet from an 18-foot deep seepage pit into an unconfined aquifer, and 138 feet from a 59-foot deep injection bore into a confined aquifer was observed. Bales et al. (1995) conducted a field study on the transport of bacteria and virus in a glacial outwash (medium to coarse sand with some gravel) aquifer at Cape Cod, MA. Their results demonstrated biocolloids travel in a fairly narrow plume in sandy (relatively homogeneous) media, with virus concentration dropping below detection limit several feet away from the source and with bacteria concentration above detection limits persisting over longer distances.

Column Studies

In an investigation conducted by Girolimon (1981) approximately $2X10^6$ *E. coli*/100mL remain in percolating wastewater after 50 inches of vertical travel through columns of very gravelly coarse sand (Malaga soil series substratum material) from Rock Island, Washington. An average of 20% of the *E. coli* broke through with the initial pore volume. The rapid breakthrough of *E. coli* and the soil data suggested extensive macropore flow was occurring. These findings agree with in a column study by Smith et al. (1985), who suggested that movement of bacteria and water in the undisturbed columns was occurring along macropores and by-passing treatment.

Results by Ziebell et al. (1974) in column studies indicated that 24 inches of coarse sand will remove large number of fecal indictors and pathogens but a deeper amount would be necessary for complete removal. Flow regime and soil temperature affected the removal process, in part indirectly, by inducing early soil clogging at low temperatures. Removal below normal detection levels was generally not achieved, especially during the early weeks of operation of the columns (the first 100 days). Similar findings were offered by Kristiansen (1981), who found considerable reduction of total bacteria with depth in the sand filter with the most developed clogging layer and almost no reduction in the sand filter with the least developed clogging layer.

In a column study using various grain sizes (fine to coarse) of clean quartz sand, Fontes et al. (1991) found that larger size bacteria had broader breakthrough peaks, which they attributed to size exclusion. All of the variables examined significantly affected bacterial transport, but mineral grain size had the strongest effects over the ranges examined. The results of their study indicated that, even in cases of efficient filtration, significant numbers of bacteria could be transported through porous media.

System Design Considerations

The soil-clogged layer, present in a mature operating SSAS, is an important feature for removal of bacteria from percolating wastewater in coarse-textured soil. Ziebell et al. (1975) suggested that the effect of the soil clog is to act as a filter in that it slows the infiltration of effluent, reducing saturated flow and increasing the contact time for destruction or adsorption of contaminates. Systems in coarse soils, without an established clogging layer, are susceptible to localized overloading, resulting in saturated or near saturated flow conditions of effluent. Due to the rapid permeability of the soil, all of the effluent may infiltrate into the soil over a short length of the drainfield trench, causing localized overloading of that portion of the trench and poor treatment (Cogger, 1988).

Kristiansen (1981) investigated the distribution of bacteria within a sand-filter trench following application of septic tank effluent. The number of bacteria decreased with depth with the highest number occurring at the gravel-sand interface of the sand filter. The system with the most developed clogging showed the least number of bacteria with depth. The author concluded the clogging was important to the purification process in the on-site system, and mechanisms that reduce the clogging layer also reduce the efficiency of the system.

In research completed by Van Cuyk et al. (2001) four 3-D lysimeters were studied in sand medium to quantify the hydraulic and treatment processes during the first year of operation. Lysimeter results revealed relatively lower hydraulic retention times and vadose zone use during the first months of startup with breakthrough of fecal coliform in sand regardless of depth to ground water (24 vs. 36 inches) or infiltrative surface loading rate scenario. After 10 months of operation and clogging zone development, the percolates were of much higher quality in terms fecal coliforms (<10 org./ 100 ml.). Thus, the operational aging process appears quite important to treatment efficiency and raises questions about the treatment performance of on-site systems with discontinuous operation (e.g. at seasonal dwelling or with cyclic loading/resting operation).

These findings agree with Postma et al. 1992, which found incomplete wastewater treatment from on-site sewage systems serving seasonal-used homes, even when 5 feet of unsaturated coarse-grained outwash soil separated the drainfield from the groundwater. Elevated numbers of bacterial indicators were observed in groundwater at both 7 feet and 20 feet away from the drainfield. A biological clogging layer did not form in the systems and may have contributed to the heavy loading of effluent in selected portions of the drainfields, thereby reducing treatment through unsaturated zone. The authors recommended a combination of pressure distribution and adequate separation depth to groundwater incorporated into the design and siting of shoreline on-site systems.

Ver Hey and Woessner (1987) reported that in a conventional gravity drainfield installed in extremely cobbly sand only a small portion of the field had received effluent, and effluent reaching the drainfield appeared to infiltrate rapidly, which resulted in poor bacterial removal. The authors concluded that conventional gravity systems are ineffective in treating domestic wastewater in coarse soil and recommended the redesign of systems to promote better treatment by the use of pressure distribution coupled with lining the drainfield with finer grained material.

In a study monitoring conventional pressure distribution and sand-lined trench systems in coarse textured glacial outwash soil of Pierce County, Harrison et al. (2000) suggested that biomat formation maybe the reason for the apparent increased treatment of fecal coliform over time. However, a biomat could not be identified visually during their excavations of the systems. After finding a decrease in fecal coliform concentration with soil depth in the systems studied, the authors predicted conventional pressure distribution systems in Soil Type 1A requires up to 22 feet of coarse textured native soil and the sand-lined systems requires up to 16 feet of coarse textured native soil below the sand filter medium to reduce fecal coliform to less than one per 100 ml. Due to the variable chacteristics of fecal coliform organisms, the authors noted, however, that their assumption about depths might not be entirely accurate. Girolimon (1981) made a similar estimate. Based on an *E. coli* removal efficiency achieved in very gravelly coarse sand columns without a biomat, the author suggested that approximately 46 feet of the very gravelly coarse sand was required for 100% removal of E. coli.

Uniform Distribution

For effective treatment of wastewater in coarse textured soils, unsaturated flow is critical since this controls contact between wastewater constituents and soil particles and associated biofilms, over an adequate period for treatment processes to occur (Bouma, 1975; Emerick et al. 1997, Schwager and Boller, 1997, Stevik et al., 1999; Van Cuyk et al. 2000; McCray et al., 2000). Coarse grain soils have the advantage of better hydraulic performance due to less clogging of the filter surface. However, a problem of using a coarse media can be that preferential flow paths may be produced, with an increased danger of breakthrough of bacteria (Boller et al., 1994). Porous media, which is too coarse, also lowers the wastewater retention time to a point where biological decomposition is inadequate (Stevik et al., 1999).

Intermittent dosing and pressurized uniform application of wastewater can be used to help create unsaturated flow conditions. Pressure distribution systems has been a minimum design requirement to minimize the chance of saturated wastewater flow into rapidly permeable soils, and to generally improve treatment and drainfield performance (Hantzsche, 1997). However, Harrison et al. (2000) shows that despites high levels of fecal coliform reductions in pressure distribution systems (91%) and sand lined bed (99.9%), large quantities of fecal coliform were passing through the systems (>10^3 cfus/100 ml).

To ensure adequate bacterial removal with the use of pressure distribution systems in coarse textured soils, the effects of hydraulic loading rate and dose volume must be understood. Lower treatment, as a result of increased hydraulic loading rate, has been observed in several experiments (Ziebell et al.1975; Siegrist and Boyle, 1982; Smith et al. 1985, Boller et al, 1994). It has been shown that high loading rates increases the water movement through larger pores (Thomas and Phillips, 1979; Smith et al., 1985; Huysman and Verstraete, 1993; Boller et al., 1994). Smith et al. (1985) reported that the transport of bacteria in porous media was directly related to the rate in which water was applied. The same phenomenon was observed by Huysman and Verstraete (1993) where transport of bacteria in columns was much greater when water was applied at a rate of 2 in./hour as compared to 0.3 in./hour.

Studies have shown that the dose size and frequency may be just as important for bacterial removal as the hydraulic loading rate (Schudel and Boller 1990; Boller et al. 1994; Emerick et al. 1997, 2000; Stevik et al., 1999). Siegrist and Boyle (1982) compared the intermittent filtration of 8.7 gpd/ft^2 of greywater septic tank effluent though coarse sand (E.S.=1.37 mm, U.C. =1.3) applied in either 24 or 6.6 doses/day. At the same daily loading rate, more frequent but smaller doses of effluent yielded higher removals of organic matter and suspended solids, as well as of fecal coliform bacteria.

Nor (1991) also found that the effect of less frequent dosing was pronounced in washed concrete sand (E.S.=0.33-0.93 mm and U.C.=1.42-4.52). Removal of coliform deteriorated from 3.9 log removal at dosing 24 times/day dosing down to 0.8 log removal at 4 times/day. Later, Emerick et al. (1997) conducted an experiment to assess the removal of microorganisms using shallow intermittent sand filters with a coarse sand (E.S.= 3.3 mm and U.C.=1.3) and a medium sand (E.S.=0.65mm and U.C.=3.8) 15 inches deep. They observed that an increase in the hydraulic loading rate reduced the log removal of total coliforms, and 90% removal of total coliform with a high dosing frequency (24 doses/day) and a loading rate of 1 gpd/ft^2. The authors concluded that the higher dosing frequency, with the same hydraulic load, leads to greater bacteria removal rates.

Schudel and Boller (1990) reported that, an intermittent sand filter dosed at a hydraulic loading rate of 0.25 gal/ft^2/dose after two 6-hour intervals, only 45% of the tracer had been recovered. The same filter, loaded at 0.5 gal/ft^2/dose after two 6-hour intervals, had recovered approximately 75% of the tracer. The authors suggested that hydraulic loads higher than 0.25 gal/ft^2/dose would surpass the water retention of the media and lead to a pronounced break-through.

Studying the hydraulic behavior of intermittent sand filters, later Boller et al. (1994) showed that at the hydraulic loading rates typically applied to filters, breakthrough of a conservative tracer depends strongly on the size and frequency of the doses. At a high dosing frequency (12/doses/day) and at a loading rate of 0.25 gal/ft^2/dose the tracer did not start to breakthrough until the 4^{th} dose, which was 7 hours after the first dose. At this high dosing frequency very little wastewater is applied to the filter at any one dose resulting in unsaturated film-like flow with low internal fluid velocities. When the daily loading rate was applied 3-times/day breakout occurred within 1 hour after dosing. This low dosing frequencies resulted in saturated or near saturated flow conditions with the filter at each dosing episode. The resulting saturated or near saturated flow conditions encourages bacteria movement deep within the filter reducing the number of opportunities for pore space entrapment. These results are supported by a similar study conducted by Stevik et al., 1999 who concluded the removal of bacteria though coarse media may be extremely dependent on the dose volume.

Viral Removal

The presence of enteric viruses in groundwater near on-site sewage systems has been well documented (Keswick and Gerba, 1980; Cantor and Knox, 1985; Yates et al. 1985). Because of their small size, viruses are less affected by soil pore filtration than bacteria. Like bacteria removal, virus removal is enhanced by low pH and ionic strength (Canter and Knox, 1985).

Most researchers agree that the primary mechanism of virus attenuation in soils is by adsorption onto soil particles, especially clays due to their highly cation exchange capacity. Virus adsorption depends on the strain of the virus. A different strain of the same virus may adsorb to a different extent and/or at a different rate (Bales et al. 1989; Woessner et al. 2001). Under conditions unfavorable for adsorption, such as in Type 1 soils, viruses can move away from an on-site sewage system and into nearby groundwater.

Various studies have monitored the transport of viruses in sand and gravel aquifers (Schaub and Sorber, 1977; Vaughn et al. 1983; Bales et at., 1995; Pieper et al., 1997; Deborde et al., 1998; Nicosia et al. 2001; Woessner et al. 2001). Predicting virus transport and removal in coarse grain aquifers, however, is still not well understood. Recent field experiments have begun to identify key factors affecting virus transport, such as solution chemistry, aquifer mineralogy, and preferential flow through heterogeneities, and the physical and physicochemical properties of the virus (Pieper et al., 1997; Woessner et al., 2001).

Research found that viruses could travel as fast, or faster than inorganic contaminants, and the combination of the virus sorption processes and long survival times resulted in the presence of viable seed virus for more than nine months (Deborde et al., 1998). Several authors have observed some virus breakthrough at earlier times than the conservative tracer or shortly afterwards (Alhajjar et al., 1988; Bates et al. 1989; Powelson et al., 1993; Pieper et al., 1997; Deborde et al., 1998; Nicosia et al. 2001). Deborde et al. (1999) proposed that early virus peak arrival may indicate that pore exclusion (virus particles being excluded by virtue of their size, surface charge, or low diffusivity from the smallest pore channels during the initial phases of transport), preferential flow or breakthrough curve truncation processes also influence viral transport. Rates of virus transport in sand and gravel aquifers, indicated by monitoring peak concentrations from slug injections, have been reported at 0.6 to 3 feet/day in the glacial outwash of Cape Cod, MA (Bales et at., 1995; Pieper et al., 1997) and 3 to 9.5 feet/day in fluvial sand and gravel near Frenchtown, MT (Deborde et al 1998, 1999).

Several cases of viral transport for long distance in coarse grain aquifers have been documented (Schaub and Sorber, 1977; Vaughn et al.. 1983; Deborde et al., 1998). Schaub and Sorber (1977) examined the fate and transport of coliphage f2 and enteric viruses after application of wastewater to rapid infiltration basins in Massachusetts. Coliphage f2 was observed in groundwater 92.5 feet below the point of application within 48 hours. Fifty percent of the phages, and about 10% of the enteric viruses were recovered in the groundwater. Viruses were detected at a lateral distance greater than 600 feet from their entry into the groundwater.

Generally, coliforms are not reliable indicators for viruses because of the physical differences between bacteria and viruses (Vaughn et al. 1983; Alhajjar et al. 1988; Scandura and Sobsey, 1997; Deborde et al., 1998). Vaughn et al. (1983) monitored the movement of enteric viruses and coliform bacteria from an on-site sewage system located 12 feet above a shallow sandy aquifer on Long Island, New York. Wells were installed at 11 distances between 5 and 220 feet from the system. In general, the number of positive tests for enteric viruses decreased with distance from the system. During one sampling period, samples collected at 198 feet were 9% positive for enteric viruses. Samples collected at depths of 59 feet below the surface, and 220 feet from the system were positive for viruses 7% of the time. Coliforms were rarely found in the groundwater at distances greater than 5 feet.

Changing environmental conditions can reverse initial virus removal or inactivation. Viral organisms may persist in temperatures as cold as -4^{0} F, but can be inactivated by high temperatures (exceeding 88^{0} F) (Yates, 1987). Hurst et al. (1980) and Yates et al. (1985) found temperature the most important factor in explaining virus survival regardless of other factors reviewed. Lower temperature showed higher virus survival rates. During transport, both irreversible and reversible attachment to rock and grain surface, and inactivation as a direct function of temperature occurs (Hurst et al. 1980; Yates et al. 1985; Bales et al. 1995, Pieper et al. 1997).

Heavy rainfall can induce saturated soil conditions or significant ionic strength changes (Yates, 1987). Low ionic strength (rainfall or distilled water) hinders adsorption and can even cause desorption (Hurst et al. 1980; Alhajjar et al., 1988). A result is that it is possible for previously adsorbed viruses to be eluted by the low ionic strength rainwater during heavy rainfalls, allowing them to be transported with the percolating rainwater. Nicosia et al. (2001) conducted a study to assess the removal of bacteriophage PRD1after passage through 2 feet of unsaturated fine sand from in a drainfield loaded at 1.2 gpd/ft^2. Bacteriophage PRD1 attachment was found to be reversible and the phage particles slowly desorbed over time in the sand under wet-season conditions. PRD1 was detected at a breakthrough concentration of 28.1 pfu/mL at day 2 and peaked at 3.7 X 10^2 pfu/mL at day 4 after the cell was seeded. Rainfall effects were observed to aid in desorption within the first 10 days of the study. The main mechanisms contributing to virus attenuation were inactivation, dilution and dispersion. The authors could not make a clear recommendation regarding the appropriate loading rate, however, a 50% decrease in hydraulic loading rate did not significantly increase virus removal.

Unsaturated flow increases the efficiency of virus removal due to slower average pore water velocities and increased surface contact per net distance traveled. Macropore flow and higher pore water velocities associated with saturated flow reduce adsorption efficiency as compared to unsaturated conditions. Powelson et al. (1990) studied the effects of saturated and unsaturated flow on the survival and transport of MS2 bacteriophage through columns of loamy fine sand. The author found that under unsaturated flow conditions, enhanced virus inactivation occurs. One study found virus removal in coarse sand columns to be three times greater in unsaturated conditions than in saturated conditions (Powelson and Gerba, 1994).

Several studies have shown that the presence of organic matter appears to interfere with virus adsorption (Piper et al. 1997). Some researchers have concluded that organic matter enhances virus transport by blocking virus attachment to mineral surface (Burge and Enkiri, 1978; Moore et al. 1981; Moore et al. 1982; Fuhs et al. 1985; Powelson et al. 1991; Pieper et al., 1997). Other researchers suggest that organic matter inhibits virus transport by promoting hydrophobic interactions between the virus and grain surfaces (Bales et al. 1991; Bales et al. 1993; Kinoshita, 1993).

Sand column studies have indicated virus adsorption in the sand may be affected by the presence of organic matter in applied wastewater. Green and Cliver (1975) examined adsorption of viruses in sand columns constructed to simulate mound systems. Columns treated with septic tank effluent prior to addition of viruses showed enhanced movement. After 3 days viruses had moved 18 inches, but in untreated sand only 8 inches. Clean sand retained 96% of the viruses, whereas conditioned sand retained only 50%. The authors attributed the lower adsorption to the presence of soluble organic matter in the water, which competed with viruses for adsorption sites on mineral surfaces. Lance and Gerba (1984) found that organic compounds in sewage counteracted the effect of higher salt content and decreased the adsorption of poliovirus to soil. Gross and Mitchell (1985) examined the effectiveness of sand columns, constructed to simulate a sand filter, in removing viruses applied in septic tank effluent. In columns treated with septic tank effluent for 3 months prior to introduction of viruses, viruses showed a breakthrough when virus-loading rates were increased to 33 million PFU/L. Columns that were not preconditioned with septic tank effluent showed no virus breakthrough. Most viruses were attenuated in the upper of the 1 to 1.5 inches of the columns.

Organic matter has been reported to not only hinder adsorption of viruses but also to result in elution of those already adsorbed (Canter and Knox, 1985). Results in a field study conducted by Nicosia et al. 2001 suggested minimal removal of PRD-1 may be attributed to a high organic matter in the sandy soil from septic tank effluent. The results in this study agrees with Pieper et al. 1997, who concluded high organic matter content was the primary factor promoting PRD1 transport in a contaminated sandy aquifer (Piper et al. 1997).

Field studies conducted by Powelson et al. (1993) to assess the effects of secondary versus tertiary effluent on virus removal through sandy alluvium near Tucson, Arizona found that significantly greater removal of PRD1 occurred with secondary compared to tertiary. Later, Powelson et al. (1994) conducted coarse sand column and batch studies, under more controlled conditions, to examine the degree of virus removal in secondary and tertiary effluent. The authors concluded that there appeared to be no virus-removal benefit in tertiary filtration (reduced turbidities to 5.0 ntu) compared to secondary effluent (turbidities 8.2-17 ntu) prior to soil treatment.

System Design Considerations

A study on the survival and transport of a model entervirus (BE-1) in four on-site sewage systems (3 conventional gravity and 1 pressure distribution system) by Scandura and Sobsey (1997) determined that the risk of viral contamination is greater in the most coarse (sand) soils, when water tables are most shallow (smallest vadose zones or unsaturated soils) and in winter when temperatures are at the lowest. Their results indicated that system design was a less important factor in the efficiency of virus reductions by on-site sewage systems than soil properties and the depth of the vadose zone. Poor reductions of viruses were indicated by increase in normally acidic water pH levels and by the presence of phosphorous and reduced nitrogenous compounds in ground water. However, wastewater nutrients were found not to be consistently good predictors of virus contamination.

Previous sand columns studies conducted by Green and Cliver (1975) and Gross and Mitchell (1985) have shown that the sand has some ability to adsorb viruses. Green and Cliver (1975) described a mound system with sandy fill material, which was efficient in the removal of poliovirus. They detailed the essential criteria for effective virus removal and concluded with proper design, and operation, mounds using 2 feet of sandy fill yielded effluents, which presented no health hazards from human enteric viruses. Although the viruses broke through their sand columns study, Gross and Mitchell (1985) reported an average virus removal of 99.996% was achieved. Because of the large number of viruses held in the biologically active upper layer of the filter, the authors concluded that the biological action of the filter was an important mechanism in virus removal. Valandingham and Gross (1998) used MS2 bacteriophage as an indictor of virus transport in sand filter columns (medium concrete sand E.S.= 0.32 mm and U.C.=2.2) of varying diameters and 2 ft in depth. They found that the bacteriophage was removed with an efficiency of 99.636% when the system was hydraulically loaded at 1.25 gpd/ft^2.

Higgins et al. (2000) reported 98.9 percent removal of MS2 virus particles within the first 2 feet of medium sand in gravity flow sand-lined trenches receiving septic tank effluent at 0.74 gpd/ft^2. Five feet of sand was needed to achieve 99.9 percent removal of the viruses. Since the sand media pore size would allow easy passage of single unadsorbed viruses, the authors attributed the removal of virus particles with passage through the sand due to the concurrent removal of suspended organic matter through the filtering process.

An eleven-month-old soil clog formed naturally at the gravel-soil interface in single grain sand under a gravity flow drainfield reported by Alhajjar et al. (1988) could not stop poliovirus from reaching the underlying groundwater. Recent laboratory and field studies of existing on-site sewage systems (non-uniform distribution) using conservative tracers and microbial surrogate measures found that episodic breakthroughs of virus can occur in the systems, particularly during early operation (Van Cuyk et al. 2001). Lysimeter results revealed relatively lower hydraulic retention times and vadose zone use during the first months of startup with breakthrough of MS-2 and PRD-1 viral surrogates in the sandy soil regardless of depth to ground water (24 vs. 36 inches) or infiltrative surface loading rate scenario. After 10 months of operation, the percolates were of much higher quality in of terms indigenous fecal coliforms (<10 org./ 100 ml) and specific pathogens (non-detect) as well as the viral surrogates. Thus, the operational aging process appears quite important to treatment efficiency and raises questions about the treatment performance of on-site systems at start-up or with discontinuous operation.

Emerick et al. (1997) conducted an experiment to assess the removal of virus in shallow intermittent sand filter with coarse sand (E.S.= 3.3 mm and U.C.=1.3) 15 inches deep. They observed that an increase in the hydraulic loading rate reduced the log removal of indigenous coliphages. They concluded that the higher dosing frequency, with the same load, leads to greater virus removal rates. Later, Emerick (2000) reported similar results in MS2 virus removal when increasing the dosing frequency of primary effluent applied to sintered-glass filter columns (E.S.=1.5 and U.C.=1.0) at a loading rate of 1.57 gpd/ft^2. At the same loading rate, increasing the dosing frequency from 1 to 48 times per day resulted in an increase in virus removal from 0.3 to 2.3 log in the absence of bacteria, and from 0.8 to 4.6 log in the presence of bacteria. At a dosing frequency of 48 times/day, virus removal immediately and markedly decreased following removal of the top 1 inch of medium, resulting in a virus removal reduction from an average of 4.6 log to 2.1 log, which was similar to that of the bacteria-free system. Filter depth also appeared to influence virus removal, with a greater depth resulting in higher virus removal.

Review of all factors impacting upon virus removal suggests that alternative practices can enhance removal. Pretreatment to reduced BOD_5 to low levels before soil dispersal may enhance adsorption. Near-surface dispersal is favored because clay content of coarse-grained soils is typically highest in the surface horizons and because soil organic matter content would be higher there in all soils. Pressure distribution would enhance removal by maintaining low flow velocities at all points in the field, as opposed to the localized overloading which typically occurs in a conventional gravity system. A high dosing frequency (greater than 12/doses/day) is suggested since conventional dosing frequencies used for BOD5 and/or TSS removal (i.e., 4 doses/day) are not optimal for removing virus.

Nitrogen Removal

Nitrogen in its nitrate form is recognized as an acute chemical contaminant in drinking water. High concentrations of nitrate can cause methemoglobinemia in infants and pregnancy complications. For this reason, the US EPA has established a maximum contaminant level (MCL) of 10 mg/L nitrate as nitrogen in drinking water. Nitrate is recognized as the most common groundwater contaminant. Due to growing anthropogenic sources, nitrate pollution is increasing. Also, increases in nitrate loading to estuarine and marine ecosystems can contribute to algal blooms leading to eutrophication.

Septic tank effluent contains a substantial quantity of nitrogen in the forms of ammonium-nitrogen and organic matter nitrogen. Nitrogen in septic tank effluent occurs about 80 percent as inorganic nitrogen with ammonium-nitrogen dominating (Walker et al., 1973a; Andreoli et al. 1979). Inorganic nitrogen commonly occurs at concentration ranging from 30-111 mg/L in septic tank effluent (Walker et al. 1973a; Andreoli et al. 1979). These nitrogen compounds are likely to oxidize to nitrate in unsaturated coarse textured soils.

Previous studies indicate that in most aerobic soils a high degree of biological nitrification can be expected, especially in coarse-textured soils (Walker et al., 1973; Whelan and Barrow, 1984; Whelan 1988; Reneau et al. 1989; Robertson and Cherry, 1995; Wilhelm et al. 1996; Harman et al., 1996). Nitrate is not readily removed from rapidly permeable soils before it reaches ground water because oxygen is present and total organic carbon concentrations are too low to sustain intensive microbial activity (Wilhelm et al., 1994). In such cases dilution is the only form of nitrate treatment between the system and the groundwater.

Girolimon (1981) demonstrated by using soil columns that the Malaga soil series substratum (very gravelly coarse sand) in Rock Island, Washington is not an effective medium for nitrate removal. The presence of a saturated zone did not improve removal. In fact, in most cases, an increase of nitrate was noted in the percolating wastewaters.

Generally, near complete nitrification is achieved in coarse textured soils, and nitrification is normally very rapid occurring in the first 12 inches below the infiltrative surface. In a study on the sandy soils of Wisconsin, Walker et al. (1973) observed significant nitrification of ammonium-nitrogen within four inches below the infiltrative surface and after effluent residency of only a few hours, in well aerated unsaturated zones below several drainfields. Nitrate concentrations were reported as high as 40 mg/L in the upper 12 inches of the aquifer adjacent to an on-site system, but decreased to approximately 10 mg/L at 230 feet down gradient. Based on the results, the authors suggested that in sands the only active mechanisms of lowering the nitrate level is by dilution with uncontaminated groundwater.

Whelan and Barrow (1984a) observed nitrate concentrations in soil solution as high as 224 mg/L at a depth of 5.5 for black water seepage pits in a Karrakaata sand (Inceptisol) of the Swan Coastal Plain in Australia. In these coarse sands, the authors concluded that all of the nitrogen added as septic tank effluent was moving into the groundwater except that lost to plant uptake.

Whelan (1988) examined nitrogen concentration in soil and soil solutions below a seepage pit in a calcareous sand (Xeropsamment) in Australia. Most ammonium-nitrogen in the septic tank effluent was converted to nitrate within 20 inches of the seepage pit. Levels of nitrate at the deepest sampling point 26 feet below the seepage pit were over 50 mg/l. The high nitrification rate also reduced the pH from 9 to 5.5, which would adversely affect potential denitrification activity. These data indicate that in well-drained soils nitrification occurs immediately below the system, denitrification does not adequately remove nitrate and the most probable mechanism for reducing the nitrate concentration in groundwater is by dilution.

Approximate times for septic tank effluent to pass through the unsaturated zone to ground water range from a few hours to fifty days, depending on the volume of effluent and the distance to ground water (Robertson et al. 1991; Robertson, 1994; Robertson and Cherry, 1995). Once in ground water, a plume develops and moves with ground water flow at a rate similar to the groundwater velocity. In settings such as sand and gravel aquifers, low dispersion often maintains high nitrate concentrations for considerable travel distance. Studies have indicated effluent plume lengths of 328 to 1400 feet (Walker et al. 1973; Robertson et al., 1991; Harman et al. 1996; Wilhelm et al. 1994). These authors' results demonstrate that for many unconfined aquifers, the minimum setback distance allowed from on-sites systems to wells (100 feet) should not be expected to be adequately protective of well water quality in situations where nitrate is not attenuated by chemical or microbiological processes.

After organic-nitrogen or ammonium-nitrogen from the septic tank effluent has been oxidized to nitrate, denitrification may occur. Denitrification is the bacterial reduction of nitrate and nitrite to gaseous nitrogen (N_2) or nitrous oxide (N_20) and is considered to be the most important reaction that attenuates nitrate in groundwater. Most denitrifying bacteria are facultative anaerobes, and thus denitrification occurs only under anaerobic conditions or conditions of reduced oxygen availability. In addition, most denitrifying bacteria couple organic carbon oxidation and nitrate reduction to gain energy, so a supply of readily labile (biodegradable) organic carbon is usually required for denitrification to occur (Korom, 1992).

In groundwater settings, a lack of labile organic carbon is the most common limitation to denitrification (Wilhelm et al. 1994; Aravana and Robertson, 1998). Starr and Sawhney (1980) determined that the concentration of organic carbon decreased and leveled off between 24 and 36 inches in a drainfield located in coarse sand. This change in organic carbon concentration suggests that the number of heterotrophic bacteria is low at this depth. Their data suggested that it would be improbable that the number of denitrifying bacteria would increase sufficiently at depths greater than 36 inches.

Starr and Gillman (1993) investigated the importance of organic carbon in controlling the occurrence of denitrification in two shallow sandy aquifers in Ontario, Canada. They found groundwater denitrification where the water table was within 3.2 feet of the surface, but little denitrification in a similar aquifer with a water table 16 feet from the surface. The authors suggested that the proximity of the groundwater to surface soils controlled the abundance of dissolved organic carbon and the extent of denitrification in the groundwater.

Chen and Harkin (1998) found denitrification occurring in an aquifer with depleted dissolved oxygen underlying a dosing system and eliminated 29.4% of the nitrogen initially applied. The authors suggested that with sufficient nitrate supplied from wastewater as an electron acceptor, the occurrence of denitrification appears to be strongly encouraged in shallow aquifers near on-site systems if the oxygen diffusing in from soils can be depleted (e.g. by organic loadings from septic tank effluent). However, in properly functioning on-site sewage systems with coarse textured soils, minimal denitrification can be expected, because aerobic (not anaerobic) conditions should persist and the supply of labile carbon is not replenished (Walker, 1973; Robertson et al, 1991; Starr and Gillman 1993).

Roberson et al. (1991) documented a capacity for groundwater nitrate removal in conditions associated with a shallow, riparian water table. They used more than 250 monitoring wells to examine on-site sewage system plumes and groundwater nitrate movement from two systems in sandy aquifers in Ontario Canada. One site was entirely within uplands and the water table was always greater than 6.6 feet from the surface. Negligible groundwater nitrate removal was noted throughout the entire 426 feet monitoring network, even though parts of the plume encountered dissolved oxygen levels less than 1 mg/l. At the other site, the monitoring network extended 66 feet from the on-site system and ended at a river. Again, negligible removal was noted for most of the plume. However, in the last 6 feet of travel, as the water table approached the ground surface just before discharging to the river, the plume passed through a zone of organic carbon-rich, anaerobic sediments and the nitrate concentration in the plume declined from 20 mg/l to less than 0.5 mg/L. The authors suggest that the removal was generated by denitrification.

A supply of labile organic carbon may not be a universal requirement for denitrification to occur in ground water. Some studies have reported substantial groundwater denitrification in aquifer zones dominated by pyrite rich deposits. In these zones sulfide or ferrous iron may serve as the energy source for denitrification, rather than labile carbon (Kolle et al.1985; Pedersen et al., 1991; Postma et al., 1991; Korom, 1992). It is also possible that both reactions, oxygen of organic matter and oxidation of pyrite, could be occurring simultaneously at some sites (Korom, 1992). In a groundwater monitoring study of nitrate from a large on-site sewage system plume, Aravana and Robertson (1998) observed that about 30% of nitrate loss was attributable to oxidation of reduced sulfur, with the remaining 70% due to oxidation of organic carbon. Stenheimer et al. (1998) attributed nitrate loss to autotrophic denitrification (non-organic food source) in a loess soil, with ferrous iron being the electron donor.

Several northwestern studies have attributed elevated levels of ground water nitrate to on-site sewage systems (Adolfson et al., 1985; Quan et al., 1974; Prins and Lustig, 1988). Quan at al. (1974) reported that from 8 to 10 million gallons per day of effluent is introduced from on-site sewage systems into a 30 square mile area of predominately coarse-grained soil in East Portland, OR. They reported nitrate levels from 5 to 12 mg/L in shallow groundwater, which eventually reached a surface drain (Columbia Slough System). Much lower levels of nitrate (<1mg/L) were recorded in the deeper aquifers and in the shallow ground waters up gradient of East Portland.

An evaluation of records of chemical analyses of 98 wells in the glacial outwash soil of Clover/Chamber basin over a 30-year period by DeWalle et al. (1980) showed high nitrate concentrations (mean 1.68 mg/L and a maximum 10.4 mg/L) in the unsewered areas and much less in the sewered areas. High nitrate concentrations were present primarily in shallow wells (up to 328 feet deep) in unsewered areas. The nitrate concentrations increased substantially in the unsewered areas and much less in the sewered areas during the 30-year period.

A similar trend was observed in the glacial outwash Rathdrum Prairie Aquifer of Idaho, where nitrate concentrations in well waters increased from less than 1 mg/L before 1970 to 6 to 12 mg/L in 1976 (Prins and Lustig, 1988). The increase in nitrate concentration was attributed to rapid and extensive housing development, which relies primarily on on-site systems.

Ryker and Jones (1995) reported nitrate concentrations are generally lower at greater depths in ground water of the Central Columbia Plateau. 26% of wells less than 300 feet deep have nitrate concentrations exceeding the EPA MCL of 10 mg/l, whereas only 8% of wells deeper than 300 feet have nitrate concentration exceeding the MCL. Nitrate concentrations in the regional ground water system vary greatly but have generally increased, due to increased irrigation and use of nitrogen fertilizers.

In a later Central Columbia Plateau ground water quality study, Williams et al. (1998) reported concentrations of nitrate in about 20 percent of all wells exceeded the EPA MCL (10 mg/L). The primary source of nitrate was agricultural fertilizers, however, other sources included on-site sewage systems. The study indicated deeper groundwater, which is farther from sources of nitrate applied on the land surface, is less susceptible to contamination. Nitrate concentrations were generally highest in the shallow wells in irrigated area, including many domestic wells and shallow public supply wells. The average nitrate concentration in the regional shallow groundwater was 6 mg/L or more. The authors noted that concentrations may be beginning to level off in some areas as a result of fertilizer use leveling off since 1985, however, in many areas the rising trend continues.

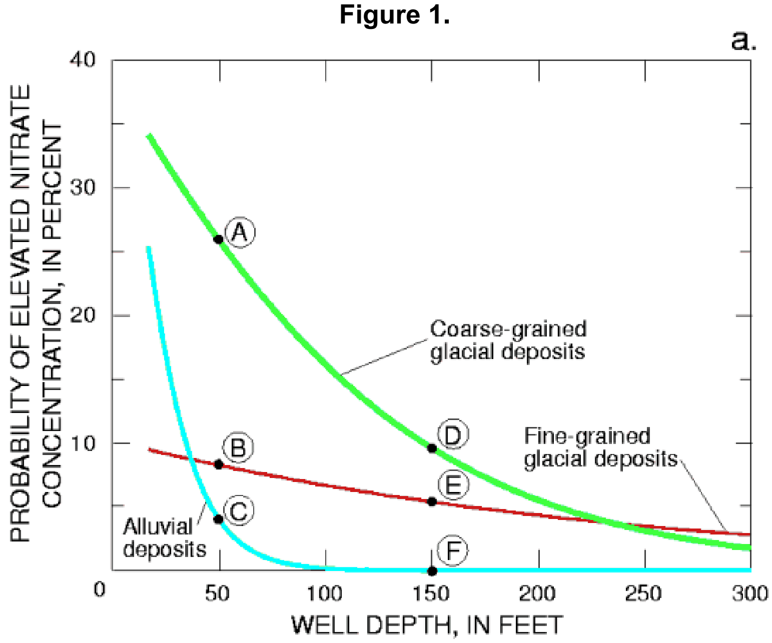
Researchers have used different approaches to quantify or predict nitrate distribution in unsewered areas. Hantzsche and Finnemore (1992) drilled several wells in three different unsewered developments in coarse soils and reported mean nitrate concentrations of 4.5 to 13.9 mg/L. Concentration in individual wells ranged from less than 2 mg/L to 65 mg/L. Quan et al. (1974) sampled several domestic wells in a deep sand and gravel aquifer and found concentrations between 5 and 12 mg/L. Harmsen et al. (1996) installed multilevel wells along two hydrologic transects in two separate unsewered subdivisions with lot sizes ranging from 0.5 to 0.7 acres. Concentrations of nitrates ranged from 5 to 15 mg/L, with average concentrations to 6 to 8 mg/L.

The Minnesota Pollution Control Agency (2000) conducted a study to compare ground water quality beneath sewered and unsewered residential areas of Baxter, Minnesota and to evaluate groundwater quality within on-site sewage plumes in a shallow sand aquifer. The researchers found that concentrations of nitrate were higher in unsewered areas than in sewered areas (2.0 vs. 0.78 mg/L). Only one domestic well exceeded the drinking water standards for nitrate of 10mg/L in the unsewered area and concentrations of most other chemical were statistically equal between the two areas. Nitrate concentrations were highest in the upper 15 to 20 feet of the aquifer, then decreased rapidly with depth. The authors noted that denitrification most likely accounted for the decrease in nitrate with depth.

In a study analyzing general water-quality conditions in the Puget Sound Basin, Tesoriero and Voss (1997) found nitrate to be the most widespread contaminant. Statistical models (Tesoriero and Voss, 1997; Erwin and Tesoriero, 1997) were created to predict which areas are most likely to become contaminated if source of contaminants are present (susceptibility) and at the greater risk of contamination, based on current land-use practices (vulnerability). Well depth, surficial geology, and land use were the factors that significantly correlated with elevated nitrate concentrations and were used in the models. Nitrate data from more than 3000 wells were used to develop and validate the models. The authors found shallow wells (less than 100 feet deep) with coarse-grained glacial surficial deposits are the most susceptible to elevated nitrate concentration both because they tend to received water with short flow paths, and these parts of the aquifer system are more likely to have oxic water. This was attributed to rainfall or applied irrigation water, which seeps relatively easily through coarse-grained sediments and can transport nitrate to ground water. Conversely, wells with alluvial and fine-grained glacial surficial deposits likely represent longer flow paths and are more likely to have water that favors nitrate reduction.

Tesoriero and Voss (1997) categorized the surficial geology into three different deposits found in the Puget Sound Basin; coarse-grained glacial, fine-grained glacial (predominantly till), and alluvial deposits. The probability that a well has an elevated nitrate concentration was related to well depth for each of the types of surficial geology (Figure 1). The probability of an elevated nitrate concentration decreases much more quickly with depth in the coarse-grained glacial deposits than does the probability of oxic water, suggesting that nitrate reduction is not a major factor limiting the transport of nitrate in this setting. In the alluvial deposits, dissolved oxygen probabilities decrease quickly with depth suggesting that some of the rapid decrease in nitrate probabilities with depth may be due to nitrate reduction.

Figure 1.



Shallow wells with coarse-grained glacial surficial deposits (for example, well A) are most susceptible to elevated nitrate concentrations. (USGS FS-061-97)

While Tesoriero and Voss (1997) showed that shallows wells with coarse-grained glacial surfical deposits are most susceptible to elevated nitrate concentrations, Nolan (1999) reported nitrate contamination of groundwater greater than about 200 feet deep is unlikely, even in high-risk areas. Using a multivariate logistic regression model, the characteristics of nitrogen loading and aquifer susceptibility to contamination were evaluated by Nolan (2001) to determine their influence on contamination of shallow ground water by nitrate. Based on the model, the author showed that the likelihood of nitrate contamination of groundwater increases in well-drained soils. This result agrees with the previous mentioned research of Tesoriero and Voss (1997). Nolan (2001) also reported the likelihood of nitrate contamination increases as the depth to seasonally high water table increases. This result agrees with findings by Burkart et al. (1999), who observed a positive correlation between a seasonally high water table and nitrate concentration in shallow, unconfined aquifers. This was attributed to very shallow depth to ground water creating anoxic conditions, which promote denitrification. Denitrification is fueled by organic matter and selected reduced minerals under anoxic conditions (Korom, 1992; Starr and Gilliam, 1993; Chen and Harkin, 1998). Increasing depth to the water table reduces the likelihood that soils are saturated, lessening denitrification potential and increasing the likelihood of nitrate contamination of ground water. The author concluded nitrate contamination is not caused by any single factor but depends on the combined, simultaneous influence of factors representing nitrogen loading sources and aquifer susceptibility characteristics.

System Design Considerations

The clogging layer and the underlying soil become sinks for nitrogen, by the incorporation of nitrogen into proteins and polysaccharides by microorganisms and by adsorption of ammonium onto the surfaces of organic matter (Walker et al. 1973a). In properly designed and operated systems, the lower sections of the biomat are subjected to aerobic soil conditions and the rate of mineralization approximates the rate of accretion, minimizing long-term nitrogen removal by the biomat (Kristiansen, 1991).

Bicki (1998) observed elevated concentrations of nitrate-nitrogen (23-37 mg/L) above background levels (9-22 mg/L) in ground water following applications of hydrogen peroxide to clogged soil absorption systems, generated as a result of oxidation of organic–nitrogen and ammonium-nitrogen stored in the crust and underlying soil. The nitrate-nitrogen concentration of soil solution samples generally decreased with distance away from the distribution box, the point of hydrogen peroxide. This suggests that oxidation of the biomat may not be uniform across the absorption trenches, resulting in variable nitrate-nitrogen concentration in the soil solution.

Whelan and Barrow (1984) examined nitrogen concentrations in soil and soil solutions below 7 seepage pits and drainfields in Australia. Soils were composed of greater than 90% sand. In systems where the water table was deep, a large increase in nitrate was reported just below the clogging mat. In some cases a subsequent decrease in ammonium-nitrogen was observed, however in other systems decreases did not occur until deeper in the profile. In systems in which the water table was within 3 feet of the bottom of the seepage or drainfield, distribution of nitrogen depended upon the age of the system. In systems younger than 4 years, a clogging layer had not formed at the far end of the drain and nitrification was occurring prior to effluent discharge. In the older systems, with completely saturated drainfields, nitrification did not occur.

Postma et al. (1992) found incomplete wastewater treatment from on-site sewage systems serving seasonal-used homes, even when 5 feet of unsaturated coarse-grained outwash soil separated the drainfield from the groundwater. Nitrate concentrations were often three to four-fold greater than the drinking water standards at wells 20 feet from the drainfields. Immediately preceding occupation, the ground water located 6.6 feet down gradient of the drainfields contained less than 2 mg/L of nitrate. These concentrations rose to averages of 20-to 50 mg/L nitrate when the homes were occupied, and a concentration as high as 115 mg/L nitrate was observed. Biological clogging mat did not form in the drainfields and may have contributed to the heavy loading of effluent in selected portions of the drainfields, thereby transport of nitrate through the unsaturated zone.

Pressure distribution of septic tank effluent has been required in Type 1 Soils to eliminate the problem of localized overloading in rapidly permeable soils, and to facilitate unsaturated flow and improve soil wastewater contact. The most common method of wastewater treatment in these soils is the sand-lined bed or trench system with pressure distribution. Most of the nitrogen in sand filter effluent is typically in the nitrate form.

Kristiansen (1981) examined the fate of nitrogen in sand filter trenches and found insignificant amounts of nitrogen to be removed from effluent passed through gravity sand-lined trenches. The author suggested that to reduce nitrate contents in sand filter effluent, the system should be designed with equal distribution of effluent, intermittent loading, and filter material with a larger cation exchange capacity than sand. Recycling the effluent back into the septic tank for denitrification was also suggested.

In a study to evaluate nitrate loading to groundwater in sandy soil areas of Wisconsin, Shaw and Turyk (1994) found nitrate concentrations ranging from 21 to 108 mg/L (average of 31 to 34 mg/L) in 14 pressure-dosed drainfield (mounds, at-grade, and conventional pressure distributions systems. No significant difference between the nitrogen treatment efficiency of mound, in ground pressure distribution, or at-grade systems were found. All 14 systems resulted in groundwater nitrate exceeding the drinking water standard of 10 mg/1. The authors concluded that minimal nitrate removal occurred in pressurized systems located over sandy media.

In a field study to compare the total nitrogen removal in conventional pressurized and gravity flow sand lined beds installed in the sandy soil of the Pinelands region of New Jersey, Bunnell et al. (1999) found no significant difference in total nitrogen removal between system types. Average total nitrogen removal rates of 40 and 48% were found for eight pressure distribution and 11 gravity flow systems, respectively. Nitrate nitrogen was the dominant form of nitrogen in the sand fill of gravity and pressure distribution systems with no additional change in nitrogen occurring within the sand fill. The lack of conditions suitable for denitrification was the reason given for no nitrogen removal in the sand fill or at the sand fill/native soil interface of the majority of systems monitored. The study concluded that pressure distribution in sand fill did not appreciably increase nitrogen attenuation above that achieved with a conventional gravity system. These results are similar to those of Shaw and Turyk (1994) who concluded that mounds, at-grade and subsurface pressure distribution systems on sandy soils do not remove a significant amount of nitrogen from domestic wastewater.

A study was conducted in the Clover/Chamber Creek aquifer region of Pierce County by Harrison et al. (2000) to assess the treatment performance of three on-site systems, where effluent flow from each system's septic tank was split to deliver half to a conventional pressurized distribution system and half to a sand lined trench system in Type 1 soils. Slight improvements in total nitrogen removal were found in the sand lined trench systems (60% removal) compared to the pressure distribution systems (44% removal). Higher levels of nitrate, however, were found in ground water beneath the sand lined trench systems (21 mg/L) compared to the pressure distribution systems (9.3 mg/L). The majority of the nitrogen fraction below the pressure distribution systems was in the form of organic-nitrogen and ammonium-nitrogen (79% of the total). The authors attributed the substantial removal of total nitrogen from the sand lined trench systems to denitrification, filtering or adsorption. The results of the pressure systems are consistent with the findings by Chen and Harkins (1998), who reported an average total nitrogen removal rate of 44.5% in three pressure dosing systems in Wisconsin, however, the results of the sand-lined trench systems showed a much higher total nitrogen removal rate than reported elsewhere in the literature.

Atkins and Christensen (2001) reported a sand lined bed reduced total nitrogen by an average of 26% (range 8%-59%) whereas an intermittent sand filter average total nitrogen reduction was 34% (range 9%-48%). In a study reported by Loomis et al. (2001) reductions in total nitrogen ranged from 8 to 23% for various types of intermittent sand filters and appeared to be greater during the cold season. No appreciable total nitrogen reduction was observed in a bottomless sand filter that received recirculating textile filter system effluent. The at-grade recirculating sand filter achieved the highest total nitrogen reductions (average 75 and 70 total nitrogen reduction for warm and cold seasons, respectively and the mean effluent concentrations were 11 and 16 mg/L, respectively), the best of any of technologies investigated in the study.

Phosphorus Removal

In contrast to nitrate, phosphorus is not directly toxic to humans, but has been shown to be involved in several water quality problems related to eutrophication than can impact human or animal health. Also, unlike nitrate, phosphorus is not very mobile in groundwater and there are no gaseous pathways for its loss from soils. Situations that involve rapid phosphorus transport to surface water are reasonably well-understood and generally related to siting of on-site systems in coarse textured soils and hydrologic settings.

Most phosphorus goes into the septic tank in organic forms, but 80% of the total phosphorus in the tank effluent is in the orthophosphate form and is readily adsorbed to soils, which contain reactive Fe, Al, or Ca compounds (Wilhelm et al. 1994). The primary processes in phosphate attenuation are absorption and precipitation (Jones and Lee 1979; Whelan and Barrow 1984; Reneau et al. 1989; Wilhelm et al. 1994). At low concentrations (<5 mg/L), the phosphate ion is chemically sorbed onto the surfaces of iron and aluminum minerals in strongly acid to neutral systems and on calcium minerals in neutral to alkaline systems. As phosphorus concentrations increase, phosphate precipitates form (Reneau et al. 1989; Wilhelm et al. 1994; Robertson et al. 1998).

The retention of phosphorus from on-site sewage systems is enhanced in fine-textured soils without continuous macropores that would allow rapid percolation. Conversely, phosphorus transport is enhanced in situations of highly permeable soils with low phosphate sorption capacity (e.g. deep sand with low concentrations of Al and Fe oxides) and soils with well-established macropores. Further exacerbating these situations is the placement of on-site systems at close proximity to surface waters, which decreases travel time for attenuation.

Tare and Bokil (1982) examined phosphate movement in columns from 3 to 30 inches in length. Columns were filled with a mixture of sand, silt and clay. Sand contents varied from 0 to 100% with clay contents varying from 0 to 30%. Wastewater was applied to columns for 30 days. No phosphate was observed below 6 inches in soils with greater than 20% silt and clay. In sandy soils, however, phosphate was in contact with soil particles for a shorter period of time because of increased flow rates, and phosphate moved farther in the column. The concentration of phosphate at 6 and 12 inches increased as the number of days of wastewater applications increased.

Monitoring below on-site sewage systems has shown that the amount of phosphorus transported to ground water depends on several factors such as the characteristics of the soil, the thickness of the unsaturated zone through which the wastewater travels, the applied loading rates and the age of the systems. Several authors have found that in soils with textures of sand or coarser the potential exists for significant groundwater phosphorus contamination in which the attenuation of phosphate appears to be limited (Jones and Lee, 1979; Whelan and Barrow, 1984; Ver Hey and Woessner, 1988; Reneau et al. 1989; Postma et al., 1992; Robertson et al. 1998). In addition, flow rates are generally greater is these soils, which limits the contact time between phosphate in solution and the soil particles.

Several studies of the migration of phosphate in the subsurface have found phosphate to be attenuated over short distances, in most cases movement of phosphate rarely exceed 50 feet in length within the plume and are generally less than 16 feet in length (Jones and Lee, 1979; Whelan, 1988; Robertson et al. 1991; Wilhelm et al. 1994). Most researchers agree that initially phosphorus is adsorbed to the soil. Recent studies, however, indicate that the attenuation potential of some soils may decline over long periods of time (Harman et al. 1996). This situation could increase phosphorus mobility and pose a contamination threat to ground water and nearby surface waters. Robertson et al. (1998) observed phosphate migration exceeding 33 feet in six of ten plumes investigated with phosphate concentrations elevated about 2 orders of magnitude (0.5 to 5.0 mg/L) compared to natural background concentrations. In contrast, Harman et al. (1996) observed phosphate concentrations of less than 1 mg/L within 33 feet of the drainfield for a 44-year old system serving an elementary school. At one site, monitoring over a several year period in Ontario Canada has revealed movement of the phosphate plume at a slow but detectable rate of about 3 feet per year (Wilhelm et al. 1996). This observation suggests that phosphate may travel in the subsurface when longer time periods are considered.

Ver Hey and Woessner (1987) examined orthophosphate concentrations below a drainfield placed in coarse alluvial soils (75.6% of the soil particles > 2 in. diameter). The concentrations of orthophosphate were nearly the same as the septic tank effluent even at depths of 8 to 47 feet. These data suggest that no treatment for orthophosphate was occurring in the system.

Whelan and Barrow (1984) examined phosphate concentrations in calcareous sands (>90% sand) and solutions below a seepage pit and drainfield in Australia. Elevated phosphate concentrations were observed in these sands at more than 26 feet below the soil surface. Concentrations of phosphate in the pore water were as high as those in the septic tank effluent suggesting that phosphate was not being attenuated and phosphate was leaching into the groundwater. Adsorption capacities predicted by isotherms were highly correlated with phosphate levels in the field, suggesting that soils had reached their phosphate absorption capacity. Later, Whelan (1988) observed calcareous sands have a limited capacity to store phosphate, and once the capacity is reached, phosphate in the soil solution will return to the same concentration as the septic tank effluent.

Robertson and Harman (1999) observed groundwater phosphate concentrations of 0.4 to 5 mg/L in monitored phosphate plumes from two on-site sewage systems over periods extending two to four years after their decommissioning, which persisted at levels virtually unchanged from those observed during active sewage loading. Their findings indicated the phosphate behavior in the ground water at these sites is little affected by secondary irreversible adsorption process or other slow consumption. As a result, the phosphate that is not retained in the unsaturated zone is transported into the ground water and has the potential to be persistent and mobile enough to be capable of contributing to down-gradient phosphate loading.

System Design Considerations

The design of an on-site system affects the potential for phosphate discharge to ground and surface waters. Common problems include surface ponding of effluent, either due to poor siting or management of the system, which enhances the likelihood of surface runoff of soluble and particulate phosphorus from the effluent, or later loss of phosphorus-enriched surface soils by erosion. Another problem is uneven distribution of effluent in the drainfield, which created zones that are saturated with phosphorus, as opposed to systems designed, or managed, to uniformly distribute effluent throughout the unsaturated zone. Uniform distribution results in the full use of the adsorption capacity of a much larger soil volume, and thus a longer on-site system site life. More uniform distribution will also maintain phosphorus concentration in the soil water and percolate at lower values than situations where soils are saturated with phosphorus to the point that concentration in the soil water and percolate differ little from that in the effluent.

Cost-benefit Information:

Conclusions:

A comprehensive review of the literature to address identified key issues on the subject of excessively permeable (Type 1A) soils was conducted. The following conclusions can be drawn from the information available in the literature:

1) The unsaturated zone's effect on microbial and nutrient contaminants is complex; it is difficult to predict removal efficiency. It is clear, however, that temperature, pH, pore-size distribution, water velocity, and degree of unsaturation are important parameters influencing attenuation in Soil Type 1. Numerous studies have demonstrated that bacteria, viral, and nutrient movement presents a potential problem in excessively permeable soils. The rapid flow of effluent through macropores decreases treatment because of reduced soil surface area and retention time. In this situation, inadequate treatment in the unsaturated zone might allow wastewater contaminants to enter the ground water if no mitigating measures are taken.

2) There is little research that has clearly demonstrated at what point the percent gravel fraction of the native soil results in a treatment problem. However, of the states reviewed for descriptions of rapidly permeable soils, here appears to be general agreement that the permeability is high enough in very coarse sand or coarser, extremely gravelly sands (loamy, fine, medium, and coarse) and all soil with at least 90% coarse fragments (gravel, cobbles, stones, and boulders) to require enhanced treatment in lieu of relying on these soils to treat septic tank effluent.

3) For effective treatment of wastewater in coarse textured soils, unsaturated flow is critical since this controls contact between wastewater constituents and soil particles and associated biofilms, over an adequate period for treatment processes to occur. Soil clogging causes more of the infiltrative surface to be used, produces an unsaturated flow regime in the underlying soil, and it can enhance treatment at the infiltrative

surface. When the development of the clogging layer is retarded or absent altogether, adequate treatment of pathogen and nutrients may occur. In several studies, conventional gravity flow systems have been shown to be ineffective in treating domestic wastewater in coarse textured soils because of localized overloading, which results in saturated or near saturated flow conditions.

4) Studies have shown that the removal of bacteria and viruses is enhanced by small and frequent doses in coarse textured soil. Small doses (more than 12 times/day) and uniform distribution assure good aeration and flow conditions where the water moves as a thin film over the particles surface. Such flow conditions can increase the retention time, which has been shown to be correlated to bacterial and virus removal.

5) Shallow unconfined aquifers that are overlain by coarse-grained glacial deposits (excessively permeable soils) have been found to be the most susceptible to nitrate contamination because they tend to receive water with short flow paths and these parts of the aquifer system are more likely to have oxic water. Several studies showed a positive correlation between soils with high water tables and the degree of denitrification. However, denitrification is expected to be limited by a lack of labile organic carbon and an absence of reducing environments under properly designed on-site systems. In these conditions, the declines in nitrate concentrations are largely attributed to dilution and dispersion.

6) The limited ability of conventional gravity and pressure distribution systems to achieve enhanced nitrate reductions and the difficulty in predicting soil nitrogen removal rates suggests that systems sited in Type 1 Soil with susceptible drinking water aquifers should incorporate additional nitrogen removal technologies prior to final soil discharge.

7) In general, it appears that the long distance transport of phosphorus from on-site sewage systems to surface waters is a much lower risk than nitrate transport. However, phosphate has a high mobility in coarse textured soils that are low in hydrous oxides or in situations where there is both poor effluent distribution and rapid flow away from the SSAS. At low concentrations, the phosphate ion is chemically sorbed onto the surfaces of iron and aluminum minerals in strongly acid to neutral systems and on calcium minerals in neutral to alkaline systems. The risk of phosphorus contamination, therefore, is greater in coarse textured soils without significant iron, calcium, or aluminum concentration located nears surface waters. In old systems, the attenuation capacity within the unsaturated zone diminishes and phosphate can reach ground water and move down-gradient in the contaminant plume.

References:

Abu-Ashour, J., D.M. Joy, H. Lee, H.R. Whitely, and S. Zelin. 1998. Movement of Bacteria in Unsaturated Soil Columns with Macropores. Trans. American Society of Agricultural Engineers (ASAE). 41:1043-1050.

Adolfson, Molly, L. West, and Derek Sandison. 1985. Comparative Impacts to Ground Water Clover/Chambers Creek Basin. In 5th Northwest On-Site Wastewater treatment Short Course and Equipment Exhibition. University of Washington, Seattle, WA. p. 42-54.

Alhajjar, B.J., S.L. Stremer, D.O. Cliver, and J,.M, Harkins. 1988. Transport Modeling of Biological Tracers from Septic Systems. Water Research 22(7):907-915.

Aravena, R. and W.D. Robertson. 1998. Use of Multiple Isotope Tracers to Evaluate Denitrification in Ground Water: Study of Nitrate from a Large-flux Septic System Plume. Ground Water 36(6):975-982.

This study explores the use of multiple isotopic tracers to evaluate the processes involved in nitrate attenuation in ground water. Delta15N and Delta18O are used to provide information about the role of denitrification on nitrate attenuation, and Delta34S, Delta18O, and Delta13C are used to evaluate the role of reduced sulfur and carbon as electron donors for nitrate reduction.

Atkins, L. and D. Christensen. 2001. Alternative Onsite Sewage Systems Ability to Reduce Nitrogen Discharged from Domestic Sources. . In On-Site Wastewater Treatment: Proceedings of the Ninth International Symposium

On Individual and Small Community Sewage Systems. American Society of Agricultural Engineers (ASAE). St. Joseph, MI. p. 171-181.

Four alternative sewage disposal systems were evaluated to determine their ability to reduce nitrogen. The systems monitored in this study were: a shallow pressurized trench system, an intermittent sand filter followed by drip irrigation, a pressurized sand-lined bed, and a proprietary aerobic treatment unit (Multi-flo). Systems were monitored pre and post treatment unit and from suction lysimeters and piezometers placed hydraulically up-gradient and down-gradient to the disposal component. The overall goal of the study was to measure the decrease in total nitrogen (TN) concentration in the waste stream caused by 1) the treatment unit, 2) plant uptake in the drainfield, and 3) dilution by ground water. Nitrogen reduction from the treatment units was less than 50% in all cases. Downgradient soil water samples had TN concentration 50% less than was measured in the dosing chamber. Results were not sufficient to differentiate the relative contribution from plant uptake vs. dilution for the decreased TN concentration. Overall, the intermittent sand filter system reduced TN concentration the most, and was the most consistent system for nitrogen reduction.

Bales, R.C., C.P. Gerba, G.H. Grondin, and S.L. Jensen. 1989. Bacteriophage Transport in Sandy Soil and Fractured Tuff. Applied and Environmental Microbiology. 55(8):2061-2067.

Bales R.C., S.R. Hinkle, T.W. Kroeger, K. Stocking, and C.P. Gerba. 1991. Bacteriophage Adsorption During Transport Through Porous Media: Chemical Perturbations and Reversibility. Environ. Science Technol. 25(12):2088-2095.

Bales R.C. and Li Shimin. 1993. MS-2 and Poliovirus Transport in Porous Media: Hydrophobic Effects and Chemical Perturbations. Water Resources Research. 29(4):957-963.

Bales, R.C., S. Li, K.M. Maguire, M.T. Yahya, C.P. Gerba, and R.W. Harvey. 1995. Virus and Bacteria Transport in a Sandy Aquifer, Cape Cod, Massachusetts. Ground Water 33(4): 653-661.

Bates, Clifford. 1998. Comparative Study of the Hydraulic Conductivities of Excessively Gravelly Soils and Non-Gravelly Soils. M.S. Thesis, Washington State University, Program in Environmental Science and Regional Planning.

Bicki, T. 1988. Hydrogen Peroxide Treatment of Septic Systems and Its Negative Effects on Shallow Ground Water. Ground Water Monitoring & Remediation. Fall, 1988. 108-111.

Soil-solution samples and shallow groundwater monitoring wells were utilized to monitor nitrate movement to groundwater following H2O2 application to a clogged soil absorption system. Nitrate-nitrogen concentrations in soil water and shallow groundwater ranged from 29 to 67 mg/l and 9 to 22 mg/l, respectively, prior to H2O2 treatment. Mean nitrate-nitrogen concentrations in soil water and groundwater increased and ranged from 67 to 115 mg/l and 23 to 37 mg/l, respectively, one week after H2O2 treatment was unsuccessful in restoring the infiltrative capacity of a well structured soil. Application of H2O2 to the soil absorption system poses a threat of nitrate contamination of groundwater and its usefulness should be fully evaluated before rehabilitation is attempted.

Boller, M., A. Schwager, J. Eugster, and V. Mottier. 1994. Dynamic Behavior of Intermittent Sand Filters. Water Science and Technology 28(10):99-107.

Buried filters were investigated in pilot and full scale and were operated by intermittent flushing which causes the water and the pollutant transport through the unsaturated media to be of highly dynamic nature. Various schemes of hydraulic flushing frequencies were found to be inversely proportional to loading. These findings were confirmed in a full scale plant through monitoring of the dynamic washout of inoxidized matter under different hydraulic loads. The moisture retention capacity of the filter media correlated to the grain size distribution was found to be an important parameter. COD removal and nitrification rates depend strongly on the oxygen supply to the media. In general, oxygen diffusion into the media and the air exchange, induced by intermittent flushing, is sufficient. However, when applying relatively large hydraulic loads to coarse filter grains, especially in the range above 1 mm, buried filters tend to larger breakthroughs of inoxidized matter due to short retention times and instantaneous lack of oxygen. Experiments on average treatment performance and showed that under optimized conditions even wastewaters containing relatively high ammonia contents can fully be nitrified when limestone type filter material is used. Full scale operation revealed further that careful pretreatment (e.g. septic tank) for the removal of most of the suspended solids is necessary to guarantee safe operation.

Bunnell, J.F., R.A. Zampella, M.D. Morgan, and D.M. Gray. 1999. A Comparison of Nitrogen Removal by Subsurface Pressure Dosing and Standard Septic Systems in Sandy Soils. Journal of Environmental Management. 56(3):209-219.

On-site septic systems are a source of both local and regional groundwater contamination in the United States and elsewhere in the world. Shallow groundwater and permeable soils increase the vulnerability of certain geographic areas to nitrogen contamination by septic systems. The Pinelands region, located on the Atlantic Coastal Plain in New Jersey, USA, is characterized by sandy soils, and is underlain by an extensive water-table aquifer. The Pinelands Commission, a regional land use planning and regulatory agency, permits the use of subsurface pressure dosing septic systems as an alternative to standard septic systems on undersized residential lots in the Pinelands. This policy was based on the assumption that pressure dosing systems remove a significant amount of wastewater nitrogen. To test this assumption, we completed a field study comparing nitrogen removal in subsurface pressurized and standard gravity flow septic systems on sandy soils. All systems served single family homes. We found no significant difference in nitrogen removal between system types. Average nitrogen removal rates of 40 and 48% were found for eight pressure dosing and 11 standard systems, respectively. In both types of systems, most nitrogen removal occurred between the septic tank and the first 15 cm (top zone) of the 1.2 m layer of sand fill. In the majority of both system types, no additional change in nitrogen occurred within the sand fill or 31 cm below the sand fill/native soil interface (bottom zone). The results of this study can provide the basis for reassessing land use policy in the Pinelands and may be applicable to regions of similar geologic conditions.

Burge, W.D. and N.K. Enkiri. 1978. Virus Adsorption by Five Soils. Journal of Environmental Quality. 7(1):73-76.

Burkart, M.R., D.W. Kolpin, R.J. Jaquis, and K.J. Cole. 1999. Agrichemicals in Ground Water of the Midwestern USA: Relations to Soil Characteristics. Journal of Environmental Quality. 28:1908-1915.

Canter L.W. and R.C. Knox, 1985. Ground Water Pollution from Septic Tank Systems. In Septic Tank System Effects on Ground Water Quality. Lewis Publishers Inc. pp. 333.

Chen, C.P. and J.M. Harkin. 1998. Transformation and Transport of 15N-Based Fixed N from Septic Tanks in Soil Absorption Systems and Underlying Aquifers. In On-Site Wastewater Treatment: Proceedings of the Eighth International Symposium On Individual and Small Community Sewage Systems. American Society of Agricultural Engineers (ASAE). St. Joseph, MI. p. 293-305.

Cogger, Craig. 1988. On-site Septic Systems: The Risk of Groundwater Contamination. Journal of Environmental Health 51(1) 12-16.

In recent years the potential for groundwater pollution from onsite septic systems has emerged as a serious concern in the United States. Outbreaks of disease have been traced to drinking groundwater contaminated by sewage from onsite systems. Nitrate from onsite systems also has leached into the groundwater and threatened water supplies in many parts of the country. It is important that we evaluate the extent of the groundwater threat posed by onsite systems and review the strategies that are available to limit further degradation of groundwater. Onsite systems currently are the only economically viable wastewater treatment option in many rural and suburban areas, and special efforts must be made to ensure their environmental viability as well.

Deborde, D.C., W.W. Woessner, B. Lauerman, and P.N. Ball. 1998. Virus Occurrence and Transport in a School Septic Systems and Unconfined Aquifer. Ground Water 36(5):825-834.

Federal efforts to establish reliable natural disinfection criteria for ground water supplies require the identification of appropriate indicator viruses to represent pathogenic viruses and an understanding of parameters affecting virus survival and transport in a variety of hydrogeologic settings. A high school septic system and the associated fecal waste-impacted unconfined sand and gravel aquifer were instrumented to: (1) evaluate if the concentrations of enterovirus and coliphage in this system were sufficient to allow their use as indicator viruses; (2) establish viral transport rates, transport distances, and concentrations in a highly conductive cold water aquifer. Enteroviruses were found in only two of eight assays of the septic tank effluent (0.26 and 4A virus/L) and were below detection in eight ground water samples. Male-specific and somatic coliphage were detectable in both the septic tank effluent (averaging 674,000 and 466,000

coliphage/L, respectively) and in the impacted underlying ground water, decreasing to detection limits beyond 38 m of the drainfield. Virus transport parameters in this aquifer were measured by seeding high numbers of MS2 and OX174 coliphage into the ground water and documenting their transport over 17.4 m. A portion of the seeded virus traveled at least as fast as the bromide tracer (1 to 2.9 m/d). Proposed natural disinfection criteria would not be met in this aquifer using standard 30.5 m setback distances. In addition, the virus sorption processes and long survival times resulted in presence of viable seed virus for more than nine months.

Deborde, D.C., W.W. Woessner, Q.T. Kiley, and P. Ball. 1999. Rapid Transport of Viruses in a Floodplain Aquifer. Water Research. 33(10):2229-2238.

An unconfined floodplain aquifer near Missoula, MT, was instrumented with 89 monitoring wells and 20 four-port multilevel samplers. Bromide, bacteriophages MS2, PRD1 and phi X174 and the attenuated enterovirus, polio virus (type-1 CHAT strain), were seeded into the aquifer as slug injections. Bromide transport rates ranged between 22-29 m/d. Input concentrations of the tracers and the placement of monitoring wells limited detection of bromide and polio virus to 19.4 m and the detection of three bacteriophage to 40.5 m downgradient from the injection point. After 7.5 m of transport, the calculated relative attenuations for MS2, PRD-1, phi X174 and attenuated polio virus were 49, 71, 65 and 99%, respectively. During the 72-h experiment, die-off was negligible (less than 1%) and attachment of virus to sediment surfaces resulted in the overall differences in bromide and virus behavior. Although relative attenuations at downgradient monitoring wells indicated that the virus tracers were attaching to aquifer material along the flowpath, virus peaks arrived at observation wells at rates similar to the bromide peak. The high collision efficiency of the attenuated polio virus resulted in breakthrough curve truncation. Natural attenuation of slug input virus over a "typical" source-supply set-back distance of 30.5 m would most likely not reduce virus concentrations to proposed acceptable risk levels in this or a similar cold-water high-velocity groundwater system.

DeWalle, F.B., and R.M. Schaff. 1980. Ground–Water Pollution by Septic Tank Drainfields. Journal of the Environmental Engineering Division, 106(EE3):631-646.

This study evaluated well records and water samples with corresponding element analyses obtained over a 30-year period from a densely populated Washington river basin in order to identify trends and correlations between pollution indicators. Increases in values for nitrate, chloride, and specific conductance were observed and attributed to the presence of sewage effluent from septic tank drainfields, since the deteriorating groundwater quality was most noticeable in unsewered areas. No significant correlations were noted in the sewered areas. Winter months produced the highest nitrate and coliform concentrations, which were attributed to infiltrating rainfall dissolving and leaching the contaminants downward.

DeWalle, F.B., R.M. Schaff, and J.B. Hatlen. 1980. Well Water Quality Deterioration in Central Pierce County, Washington. Journal American Water Works Association. 1980. 72:553-536.

Emerick, R.W., R.M. Test, G. Tchobanoglous, and J. Darby. 1997. Shallow Intermittent Sand Filtration: Microorganism Removal. In The Small Flows Journal. 3(1): 12-22.

Twelve shallow circular sand filters (0.38 m deep, nominal diameter of 1.2 m) were loaded intermittently with primary effluent to evaluate the effects of hydraulic loading rate (HLR) -coupled with a high dosing frequency (DF) -and filter medium characteristics on the removal of indigenous coliphages, total coliforms, turbidity, chemical oxygen demand (COD), and total suspended solids (TSS). HLRs between 0.041 and 0.162 m/d were applied during an 84-day period at a DF of 24 doses/d. Two types of filter media were investigated: medium-size and coarse sand and crushed glass. Effective sizes ranged from 0.44 to 3.3 mm, and uniformity coefficients ranged from 1.3 to 5.0. Average removal rates greater than 94, 96, and 92 percent occurred for turbidity. TSS, and COD, respectively, regardless of medium characteristics. Removal of microorganisms was found to be affected by the combination of HLR and DF, with an increase in HLR at a constant DF resulting in a decrease in the log removal of both total coliforms and indigenous coliphages. Indigenous coliphage appeared to be more sensitive to changes in HLR than seeded polioviruses.

Emerick, R.W., J. Manning, G. Tchobanoglous, and J. L. Darby. 2000. Impact of Bacteria and Dosing Frequency on the Removal of Virus with Intermittently Dosed Biological Filters. In The Small Flows Quarterly. 1(1): 36-41.

Six dosing frequencies (1, 2, 3, 12, 24, and 48 times/day) were investigated for their impact on the removal of MS2 virus from primary effluent in laboratory-scale sintered-glass filter columns. The filters were operated both with and without the presence of bacteria on the sintered glass. The hydraulic application rate was 0.064 m/day [1]. The effective size of the medium was 1.5 mm with a uniformity coefficient of 1.0. The internal surface area was 87,050 m 2 /m 3. Filter depth was 152 mm. At the constant hydraulic application rate, increasing the dosing frequency from 1 to 48 times/day resulted in an increase in the viral removal from 0.3 to 2.3 log in the absence of bacteria, and from 0.8 to 4.6 log in the presence of bacteria. At a dosing frequency of 48 times/day, removing the top 25 mm of the medium resulted in virus removal performance similar to that of the bacteria-free system. Filter depth also appeared to influence virus removal, with a greater depth resulting in higher virus removal.

Ebbert, J.C., S.S. Embrey, R.W. Black, A.J. Tesoriero, and A.L. Haggland. 2000. Water Quality in the Puget Sound Basin, Washington and British Columbia, 1996-98. U.S. Geological Survey Circular 1216. on-line at URL http://water.usgs.gov/pubs/circ/circ1144/ accessed Nov., 1997, HTML format.

Erwin M.L. and A.J. Tesoriero. 1997. Predicting Ground-Water Vulnerability to Nitrate in the Puget Sound Basin. USGS Fact Sheet FS-061-97, on-line at URL http://wa.water.usgs.gov/pubs/fs/fs.061-97/, accessed Nov., 1997, HTML format.

Flühler, H., N. Ursino, M. Bundt, U. Zimmermann, and C. Stamm. 2001. The Preferential Flow Syndrom – A Buzzword or a Scientific Problem. Preferential Flow Conference, Water Movement and Chemical Transport in the Environment, Proceedings of the 2nd Int. Symp. , American Society of Agricultural Engineers (ASAE). St. Joseph, MI. p. 21-24.

The export of surface-applied compounds or of elements residing in the solution of the soil matrix to surface and groundwater is, in most cases, a problem with a spatial scale in the order of hectares or more. Preferential flow, on the other hand, is often analyzed on scales of small field plots, soil monoliths or smaller. Reactive compounds are partly bypassing the retention compartment of the soil matrix through sub-scale pathways that are undetectable with currently used sampling techniques. The purpose of this is to bridge the scale of preferential flow processes with that of the preferential flow effects. Ultimately, this is a problem of the detection devices used for capturing the decisive soil factors and their implementation into up-scaled models.

Fontes, D.E., A.L. Mills, G.M. Hornberger, and J.S. Herman. 1991. Physical and Chemical Factors Influencing Transport of Microorganisms Through Porous Media. Applied and Environmental Microbiology. 57(9):2473-2481.

Fuhs, G.W., M. Chen, L.S. Sturman, and R.S. Moore. 1985. Virus Adsorption to Mineral Surfaces is Reduced by Microbial Overgrowth and Organic Coatings. Microbial Ecology. 11:25-39.

Geyer, D.J., C.K. Keller, J.L. Smith, and D.L. Johnstone. 1992. Subsurface Fate of Nitrate as a Function of Depth and Landscape Position in Missouri Flat Creek Watershed, U.S.A. Journal of Contaminant Hydrology. 11(1/2):127-147.

Increased nitrate concentrations in groundwater associated with the application of nitrogen fertilizers have led to inquiries concerning the fate of nitrate beneath agricultural fields. This study was conducted to identify the processes affecting the distribution of nitrate in the unsaturated and saturated zones beneath an agricultural field and to assess how each process is influenced by factors associated with slope position. Nested piezometers were installed at two slope positions at the study site in southeastern Washington, U.S.A. Unsaturated- and saturated-zone sediment cores were analyzed for water content, pH, total and soluble organic carbon, ammonium, nitrate, and denitrification potential. Waters from the piezometers showed decreasing nitrate concentrations with depth below the water table. Trends in measured parameters indicated depth intervals where the distribution of nitrate could be attributed either solely to transport or to a combination of transport and biological denitrification. Denitrification explained the distribution of nitrate in the root zone while transport explained the interval between the root zone and the water table. There was a higher potential for denitrification below the water table at the bottom slope than at the top slope. Factors associated with slope position, such as a shallow water table and impeding stratigraphic layers, may explain this higher potential. Regardless of slope position, comparing nitrous oxide and carbon dioxide production from nitrate- and carbon-amended or -unamended samples indicated that denitrifier populations present in high-potential zones are nitrate-limited. Results from spherical microsite modelling suggest that anoxic conditions are possible in the bulk sediment despite the presence of oxygenated groundwaters beneath both slope positions. Advective-dispersive transport will continue to transport nitrate through the unsaturated and saturated zones. The data from this study suggest that there is greater potential for nitrate attenuation by denitrification beneath the bottom slope than the top slope. The data also show that large masses of nitrate reside in deep subsoil vadose zones. These regions must therefore be monitored to detect threats to future groundwater quality.

Girolimon, Gary A. 1982. Migration of Nitrate and *Escherichia coli* through Malaga Substratum Material. Department of Civil and Environmental Engineering. Final Report: Pre and Post Flood Water Quality Investigation Rock Island, Washington. Washington State University. p. 44.

Green, K.M. and D.O. Cliver. 1975. Removal of Virus from Septic Tank Effluent by Sand Columns. Proceedings of the National Home Sewage Disposal Symposium. American Society of Agricultural Engineers (ASAE). St. Joseph, MI. p. 137-143.

Gross, M. and D. Mitchell. 1995. Biological Virus Removal from Household Septic Tank Effluent. In On-Site Wastewater Treatment: Proceedings of the Four National Symposium On Individual and Small Community Sewage Systems. American Society of Agricultural Engineers (ASAE). St. Joseph, MI. p. 122-131.

Hantzsche, Norman N. 1997. Wastewater Impacts on Groundwater Quality in Rapidly Permeable Soils. In 9th Northwest On-Site Wastewater treatment Short Course and Equipment Exhibition. , University of Washington, Seattle, WA. p. 175-190.

This paper presents a case study review of the design and groundwater quality impacts of a large-on-site wastewater system located in an area of rapidly permeable soils. The project site is the Bodega Marine Laboratory, an educational and research unit of the University of California's Davis campus, consists of teaching, laboratory, administrative and housing facilities located west of the community of Bodega Bay, approximately 60 miles north of San Francisco, California. Originally constructed in the 1960's, the Bodega Marine Laboratory undertook a significant expansion program in the mid-1980's, including a doubling of the laboratory and housing complex. The new buildings required significant upgrading and expansion of wastewater facilities that had consisted of a septic tank-gravity drainfield system in an area of seasonally high groundwater. Sewer connection to the Town of Bodega Bay was initially considered, but rejected due to cost and capacity limitations. Instead, an alternative location for an expanded on-site system was investigated and developed. The on-site opportunities were limited due to the large expanse of sand dunes and sensitive biological resources covering most of the site. The area finally selected for wastewater disposal was located in an area of deep, sandy soils, having rapid permeability at or near the commonly recognized limit of acceptability. Following permit approval, the new wastewater facilities were installed in 1991. Quarterly bacteriological monitoring of the groundwater near the system for the past five years provides useful data on the effectiveness and impacts of wastewater disposal in rapidly permeable soils.

Hantzsche, Norman C. and E. John Finnemore. 1992. Predicting Ground-Water Nitrate-Nitrogen Impacts. Ground Water. 30(4):490-499.

Harman, J., W.D. Robertson, J.A. Cherry, and L. Zanini. 1996. Impacts on a Sand Aquifer from an Old Septic System: Nitrate and Phosphate. Ground Water 34(6):1105-1113.

Harmsen, E.W., J.G. Converse, E.J. Tyler, J.O. Peterson. 1991. Considerations for Protecting Private Water Supply Wells in Rural Unsewered Subdivisions. In On-Site Wastewater Treatment: Proceedings of the Sixth National Symposium On Individual and Small Community Sewage Systems. American Society of Agricultural Engineers (ASAE). St. Joseph, MI. p. 206-213.

Unsewered subdivision communities in areas with highly permeable soils are at risk from groundwater pollution by nitrate-N and other contaminants. Because of the high soil permeability, water for drinking is often obtained from shallow private wells that are screened near the water table. This situation is common at subdivisions in the Central Wisconsin sand plain, where well-water nitrate-N concentrations as high as 20 mg/L are common. Factors which increase potential groundwater contamination by nitrate-N include: closely spaced homes, each with a septic tank-drainfield; N sources (such as fertilized agricultural land) up-gradient of the subdivision; a well-aerated unsaturated zone ideal for nitrification; low soil cation exchange capacity with little fixation capacity for ammonium-N; and a low soil moisture holding capacity resulting in overfilling of the root zone and leaching of N due to moderate rainfall events or over-watering of lawns. Potential contamination of a water supply well by effluent originating from a septic tank-drainfield can be minimized by excluding the drainfield from the area associated with the well capture zone. This paper will describe a computer model designed to estimate lateral and vertical separation distances necessary to prevent contamination of a well by a nearby septic tank-drainfield. Conditions necessary to apply the model to an actual situation are discussed. The factors discussed will also be of general interest for protecting water supply wells in unsewered subdivisions.

Harrison, R. B., N.S. Turner, J.A. Hoyle, J. Krejsel, D.D. Tone, C.L. Henry, P.J. Isaksen and D. Xue. 2000. Treatment of Septic Effluent for Fecal Coliform and Nitrogen in Coarse-textured Soils: Use of Soil-only and Sand Filter Systems. Water, Air, & Soil Pollution. 124(1-2):205-215.

Groundwater effluent sample collectors (zero-tension lysimeters) were installed directly below the drainfields of three residential onsite treatment systems in the Clover/Chambers Creek aquifer region of Pierce County near Tacoma, WA. The use of a split effluent delivery system from the septic tank, where half the effluent was delivered under pressure to a normal native soil-only filter system and half was delivered to a sand filter system, allowed the direct comparison of the two commonly-utilized septic systems for treatment levels. Septic tank effluent (from the septic tank) and percolating water (between 0.3 and 0.9 m beneath the effluent distribution lines) was collected between May 1991 and April 1994 on 30 occasions. Samples were analyzed for fecal coliform bacteria, nitrate, nitrite, ammonium and total reduced (Kjeldahl) nitrogen. Results of this study indicate that the use of sand filters greatly increased removal of fecal coliform bacteria and total nitrogen. Soil-only filter systems had an average of 91% removal of fecal coliforms and 47% of total N; whereas sand filter systems had an average of 99.8% removal of fecal coliforms and 80% of total N.

Higgins, J, Heufelder, G and Foss, S. 1999. Removal Efficiency of Standard Septic Tank and Leach Trench Septic Systems for MS2 Coliphage, in Proceedings of 10th Northwest On-site Wastewater Treatment Short Course and Equipment Exhibition, University of Washington, September 1999.

This paper reports the virus attenuation in sewage as it passes through various components of an on-site system. The virus used was the naturally occurring male-specific MS2 coliphage. The drainfield was constructed in medium sand and samplings occurred in lysimeters placed beneath the infiltrative surface at the time of construction. The systems were new and did not have a mature clogging mat. Reductions of MS2 were measured as follows: septic tank effluent, 75%, first 12" of soil, another 99% reduction, and very little change between 12" and 24" of soil, and a slight decrease between 24" of soil and 5.5 feet of soil. The report cautions against coupling a reduction in vertical separation and reduction in drainfield size (i.e. increased loading rates) when applying highly pretreated effluent to the soil absorption component. Research is needed to show whether impedance to formation of a clogging mat appreciably affects the ability of the OSS to remove viruses.

Higgins, J., G. Heufelder, and S. Foss. 2000. Removal Efficiency of Standard Septic Tank and Leach Trench Septic Systems for MS2 Coliphage. Small Flows Quarterly 1(2):26-57.

Howell, J.M., M.S. Coyne, and P.L. Cornelius. 1996. Effect of Particle Size and Temperature on Fecal Bacteria Mortality Rates and the Fecal Coliform/Fecal Streptococci Ratio. Journal of Environmental Quality. 25:1216-1220.

Hurst, C.J., C.P. Gerba, and I. Cech. 1980. Effects of Environmental Variables and Soil Characteristics on Virus Survival in Soil. Applied and Environmental Microbiology. 40(6):1067-1079.

Huysman, F. and W. Verstraete. 1993. Water-Facilitated Transport of Bacteria in Unsaturated Soil Columns: Influence of Inoculation and Irrigation Methods. Soil Biol. Biochem. 25(1): 91-97.

Jones, R.A. and G.F. Lee. 1979. Septic Tank Wastewater Disposal Systems as Phosphorus Sources for Source Waters. Journal of Water Pollution Control Federation. 51(11):2764-2775.

Keswick, B.K. and C.P. Gerba. 1980. Viruses in Groundwater. Environmental Sci. Technol. 14(11):1290-1297.

Kinsoshita, T, R.C. Bales, K.M. Maguire, M.T. Yahya, and C.P. Gerba. 1993. Effect of pH of Bacteriophage Transport Trough Sandy Soils. J. Contam. Hydrol. 14:55-70.

Komer, Stephen C. and Henry W. Anderson, Jr. 1993. Nitrogen Isotopes as Indictors of Nitrate Sources in Minnesota Sand-Plain Aquifers. Ground Water 31(2):260-270.

Korom, Scott F. 1992. Natural Denitrification in the Saturated Zone: A Review. Water Resources Research 28(6):1657-1668.

Kristiansen, R. 1981. Sand-filter Trenches for Purification of Septic Tank Effluent: I. The Clogging Mechanism and Soil Physical Environment. Journal of Environmental Quality 10(3): 352-357.

> This is the first of three articles on sand filter trenches for treating septic tank effluent. Three pilot plant sand filters, one heated and two at ambient temperatures, were observed to explain the relationship between clogging and soil physical and chemical environment in the sand filters. Discusses ponding rates, C/N ratio, bacteria and bacterial exudates, redox potential, and atmosphere within the sand filters.

Kristiansen, R. 1981. Sand-filter Trenches for Purification of Septic Tank Effluent: II. The Fate of Nitrogen. Journal of Environmental Quality 10(3): 358-361.

> This is the second of three articles about the use of sand filter trenches to treat septic tank effluent. Three sand filters are heated and two at ambient temperature were observed to determine the fate of nitrogen in the system. Insignificant amounts of N were found to be removed from effluent passed through the filters. Suggests equal distribution of effluent, intermittent loading, and use of a soil with a higher cation exchange capacity than sand to improve nitrogen removal in septic systems.

Kristiansen, R. 1981. Sand-filter Trenches for Purification of Septic Tank Effluent: III. The Microflora. Journal of Environmental Quality 10(3): 361-364.

> This is the third of three articles about the use of sand filter trenches to treat septic tank effluent. Size distribution and proportions of important bacterial groups are discussed, along with the biomass at different depths below the filter surface. Efficient removal of bacteria was observed in clogged absorption fields as compared with unclogged fields, suggesting that intermittent loading may reduce purification efficiency unless very small application rates are used so that flow through the sand filter remains highly unsaturated.

Krone, R.B., G.T. Orlob, and C. Hodgkinson, C. 1958. Movement of Coliform Bacteria Through Porous Media,. Sewage Ind. Wastes. 30(1)1-13.

Lance J.C., and C.P. Gerba. 1984. Effect of Ionic Composition of Suspending Solution on Virus Adsorption by a Soil Column. Applied Environmental Microbiology. 47:484-488.

Lee, R.W., and P.C. Bennett. 1998. Reductive Dissolution and Reactive Solute Transport in a Sewage-Contaminated Glacial Outwash Aquifer. Ground Water. 36(4):583-595.

> Contamination of shallow ground water by sewage effluent typically contains reduced chemical species that consume dissolved oxygen, developing either a low oxygen geochemical environment or an anaerobic geochemical environment. Based on the load of reduced chemical species discharged to shallow ground water and the amounts of reactants in the aquifer matrix, it should be

possible to determine chemical processes in the aquifer and compare observed results to predicted ones. At the Otis Air Base research site (Cape Cod, Massachusetts) where sewage effluent has infiltrated the shallow aquifer since 1936, bacterially mediated processes such as nitrification, denitrification, manganese reduction, and iron reduction have been observed in the contaminant plume. In specific areas of the plume, dissolved manganese and iron have increased significantly where local geochemical conditions are favorable for reduction and transport of these constituents from the aquifer matrix. Dissolved manganese and iron concentrations ranged from 0.02 to 7.3 mg/L, and 0.001 to 13.0 mg/L, respectively, for 21 samples collected from 1988 to 1989. Reduction of manganese and iron is linked to microbial oxidation of sewage carbon, producing bicarbonate and the dissolved metal ions as by-products. Calculated production and flux of CO sub(2) through the unsaturated zone from manganese reduction in the aquifer was 0.035 g/m super(2)/d (12% of measured CO sub(2) flux during winter). Manganese is limited in the aquifer, however. A one-dimensional, reaction-coupled transport model developed for the mildly reducing conditions in the sewage plume nearest the source beds showed that reduction, transport, and removal of manganese from the aquifer sediments should result in iron reduction where manganese has been depleted.

Loomis, G.W. D.B. Dow, M.H. Stolt, A.D. Sykes, and A.J. Gold. 2001. Performance Evaluation of Innovative Treatment Technologies Used to Remediate Failed Septic Systems. In On-Site Wastewater Treatment: Proceedings of the Ninth International Symposium On Individual and Small Community Sewage Systems. American Society of Agricultural Engineers (ASAE). St. Joseph, MI. p. 52-61. on-line at URL http://www.uri.edu/ce/wq/owtc/html/owtc_publications.html

An evaluation of the treatment performance of twelve, full-scale, innovative treatment systems was initiated in 1997 under a State of Rhode Island-funded project targeted in a priority watershed that is both pathogen and nitrogen sensitive. Loomis and Dow (1998) reported on the site conditions, constraints encountered, types of systems installed, actual measured hydraulic loading rates to these systems, targeted water quality goals, construction cost estimates, strategies for educating participating clientele groups, and startup performance results from these systems. In this paper we report on the treatment performances of one at-grade recirculating sand filter, two single pass sand filters, three Maryland style recirculating sand filters, five foam cube biofilters, and one recirculating textile filter. The data were collected over an 18 month period. All the sand filter systems studied reduced TSS and BOD5 by 90 to 99%; achieved 2.3 to 3.8 log10 reductions in fecal coliform levels; and produced TN reductions ranging from 8 to 75%, depending upon type of sand filter system and season (temperature). Mean TSS and BOD5 effluent concentrations for the foam biofilters and the textile filter were both less than 20 mg/l. TN concentrations in recirculating textile filter effluent averaged 13 and 29 mg/l for the warm and cold seasons, respectively; whereas fecal coliform concentrations averaged 3,000 and 52,500 counts/100 ml. Log10 reductions of fecal coliform for the foam biofilters averaged about 1.5 regardless of season. Mean effluent TN concentrations and percent TN reductions in the foam biofilters ranged from 28 to 61 mg/l and 10 to 23%, respectively. All systems operated hydraulically without mishap, with the exception of the recirculating textile filter that needed retrofitting about midway through the study.

Mace, Andy, David L. Rudolph, and R. Gary Kachanoski. 1998. Suitability of Parametric Models to Describe the Hydraulic Properties of an Unsaturated Coarse Sand and Gravel. Ground Water. 36(3):1998.

The performance of parametric models used to describe soil water retention (SWR) properties and predict unsaturated hydraulic conductivity (K) as a function of volumetric water content (theta) is examined using SWR and K(theta) data for coarse sand and gravel sediments. Six 70 cm long,10 cm diameter cores of glacial outwash were instrumented at eight depths with porous cup tensiometers and time domain reflectometry probes to measure soil water pressure head (h) and theta, respectively, for seven unsaturated and one saturated steady-state flow conditions. Forty-two theta(h) and K(theta) relationships were measured from the infiltration tests on the cores. Of the four SWR models compared in the analysis, the van Genuchten (1980) equation with parameters m and n restricted according to the Mualem (m = 1 - 1/n) criterion is best suited to describe the theta(h) relationships. The accuracy of two models that predict K(theta) using parameter values derived from the SWR models was also evaluated. The model developed by van

Genuchten (1980) based on the theoretical expression of Mualem (1976) predicted K(theta) more accurately than the van Genuchten (1980) model based on the theory of Burdine (1953). A sensitivity analysis shows that more accurate predictions of K(theta) are achieved using SWR model parameters derived with residual water content (Or) specified according to independent measurements of 0 at values of h where partial(theta)/(partial)h = 0 rather than model-fit theta^sub r^ values. The accuracy of the model K(theta) function improves markedly when at least one value of unsaturated K is used to scale the K(theta) function predicted using the saturated K. The results of this investigation indicate that the hydraulic properties of coarse-grained sediments can be accurately described using the parametric models. In addition, data collection efforts should focus on measuring at least one value of unsaturated hydraulic conductivity and as complete a set of SWR data as possible, particularly in the dry range.

MacKown, C.T. and T.C. Tucker. 1985. Ammonium Nitrogen Movement in a Coarse-Textured Soil Amended With Zeolite. Soil Science Society of America Journal, 49(1): 235-238.

Column experiments with Rositas loamy sand amended with erionite or clinoptilolite were conducted to evaluate the affect of natural zeolites on the adsorption of applied ammonium for unamended soil to 11.6 grams ammonium for the erionite amended soil with cation exchange capacities of 29 and 102 cmol per kilogram, respectively. Similar trends, but to a less degree, were noted for the clinoptilolite amended soil. For a given amount of zeolite amendment, ammonium in the effluent was less with erionite than with clinoptilolite. As cation exchange capacity increased, the depth of maximum accumulation decreased.

McCray, J.E., D.H. Huntzinger, S. Van Cuyk, and R. Siegrist. 2000. Mathematical Modeling of Unsaturated Flow and Transport in Soil-based Wastewater Treatment Systems. Proceeding of the WEFTEC 2000. Water Environment Federation's Technical Exhibition and Conference. Washington D.C. 20 pages.

A numerical model is used to investigate the impact of the infiltrative-surface crust on the hydraulic-treatment volume and on unsaturated transport and transformation of orthophosphate and ammonium in soil-based wastewater treatment systems (SWTS). The simulated SWTS is a subsurface trench underlain by a natural soil. Crusts at the base and on the sidewall of the trench are incorporated in the model. Unsaturated water-flow and contaminant-transport parameters are selected from the ranges of values measured in field and laboratory experiments that have been reported in the literature. The process of contaminant sorption to soil is included for both contaminants. Biochemical ammonium transformation and phosphate precipitation are simulated assuming first-order kinetics. The simulations illustrate that the presence of an infiltrative-surface crust greatly improves treatment of orthophosphate and ammonium. The infiltrative crust causes reduced infiltration velocities and a somewhat larger hydraulic-treatment volume. The slower velocities result in longer hydraulic residence times and thus allow more time for biochemical removal. Increased hydraulic volumes are due mainly to infiltration through the sidewall crust in mature systems. Slower contaminant velocities due to sorption also improve biochemical treatment. The impact of two septic-tank effluent (STE) -application methods on treatment is evaluated for an uncrusted system. Uniform application across the infiltration trench resulted in improved treatment due to a larger overall hydraulic residence time compared to a focused application in the center area of the trench. This research illustrates that numerical models are useful for gaining a better understanding of crust development and the associated impact on contaminant treatment.

McGinnis, J.A. and F. DeWalle, 1983. The Movement of Typhoid Organisms in Saturated, Permeable Soil. J. Am. Water Works Assoc. 75(6):266-271.

Minnesota Pollution Control Agency. 1999. Effects of Septic Systems on Ground Water Quality – Baxter, Minnesota. Prepared by GWMAP. p. 37.

Moore, R.S., D.H. Taylor, L.S. Sturman, M.M. Reddy, and G.W. Fuhs. 1981. Polivirus adsorption by 34 Mineral and Soils. Applied and Environmental Microbiology. 42(6):963-975.

Moore, R.S., D.H. Taylor, L.S., M.M. Reddy, and Sturman. 1982. Adsorption of Reovirus by Mineral and Soils. Applied and Environmental Microbiology. 44(4):852-859.

Nicosia, L.A., J.B. Rose, L Stark, and M.T. Stewart. 2001. A Field Study of Virus Removal in Septic Tank Drainfields. Journal of Environmental Quality. 30:1933-1939.

Two field studies were conducted at a research station in Tampa, Florida to assess the removal of bacteriophage PRD1 from wastewater in septic tank drainfields. Infiltration cells were seeded with PRD1 and bromide and the effects of effluent hydraulic loading rate and rainfall on virus removal were monitored. Septic tank effluent samples were collected after passage through 0.6 m of unsaturated fine sand and PRD1 was detected over an average of 67 d. Bacteriophage PRD1 breakthrough was detected at approximately the same time as bromide in all three cells except for the low-load cell (Study 1), where bromide was never detected. Log_{10} removals of PRD1 were 1.43 and 1.91 for the high-load cells (hydraulic loading rate = 0.063 m/d) and 2.21 for the low-load cell (hydraulic loading rate = 0.032 m/d). Virus attenuation is attributed to dispersion, dilution, and inactivation. Significant increases in PRD1 elution with rainfall were observed in the first 10 d of the study. Approximately 125 mm of rainfall caused a 1.2 log_{10} increase of PRD1 detected at the 0.6-m depth. Current Florida on-site wastewater disposal standards, which specify a 0.6-m distance from the drainfield to the water table, may not provide sufficient removal of viruses, particularly during the wet season.

Nolan, B.T., B.C. Ruddy, K.J. Hitt, and D.R. Helsel. 1997. Risk of Nitrate in Groundwater of the United States - A National Perspective. Environmental Science & Technology. 31(8):2229-2236.

Nitrate contamination of groundwater occurs in predictable patterns, based on findings of the U.S. Geological Survey's (USGS) National Water Quality Assessment (NAWQA) Program. The NAWQA Program was begun in 1991 to describe the quality of the Nation's water resources, using nationally consistent methods. Variables affecting nitrate concentration in groundwater were grouped as "input" factors (population density and the amount of nitrogen contributed by fertilizer, manure, and atmospheric sources) and "aquifer vulnerability" factors (soil drainage characteristic and the ratio of woodland acres to cropland acres in agricultural areas) and compiled in a national map that shows patterns of risk for nitrate contamination of groundwater. Areas with high nitrogen input, well-drained soils, and low woodland to cropland ratio have the highest potential for contamination of shallow groundwater by nitrate. Groundwater nitrate data collected through 1992 from wells less than 100 ft deep generally verified the risk patterns shown on the national map. Median nitrate concentration was 0.2 mg/L in wells representing the low-risk group, and the maximum contaminant level (MCL) was exceeded in 3% of the wells. In contrast, median nitrate concentration was 4.8 mg/L in wells representing the high-risk group, and the MCL was exceeded in 25% of the wells.

Nolan, B.T. 1999. Nitrate Behavior in Ground Waters of the Southeastern USA. Journal of Environmental Quality. 28(5):1518-1527.

Results of a national water quality assessment indicate that nitrate is detected in 71% of groundwater samples, more than 13 times as often as ammonia, nitrite, organic nitrogen, and orthophosphate, based on a common detection threshold of 0.2 mg/L. Shallow groundwater (typically 5 m deep or less) beneath agricultural land has the highest median nitrate concentration (3.4 mg/L), followed by shallow groundwater beneath urban land (1.6 mg/L) and deeper groundwater in major aquifers (0.48 mg/L). Nitrate exceeds the maximum contaminant level, 10 mg/L as nitrogen, in more than 15% of groundwater samples from 4 of 33 major aquifers commonly used as a source of drinking water. Nitrate concentration in groundwater is variable and depends on interactions among several factors, including nitrogen loading, soil type, aquifer permeability, recharge rate, and climate. For a given nitrogen loading, factors that generally increase nitrate concentration in groundwater include well-drained soils, fractured bedrock, and irrigation. Factors that mitigate nitrate contamination of groundwater include poorly drained soils, greater depth to groundwater, artificial drainage systems, intervening layers of unfractured bedrock, a low rate of groundwater recharge, and anaerobic conditions in aquifers.

Nolan, Bernard T. 2001. Relating Nitrogen Sources and Aquifer Susceptibility to Nitrate in Shallow Ground Waters of the United States. Ground Water. 39(2): 290-299.

Characteristics of nitrogen loading and aquifer susceptibility to contamination were evaluated to determine their influence on contamination of shallow ground water by nitrate. A set of 13 explanatory variables was derived from these characteristics, and variables that have a significant influence were identified using logistic regression (LR). Multivariate LR models based on more than 900 sampled wells predicted the probability of exceeding 4 mg/L of nitrate in ground water. The final LR model consists of the following variables: (1) nitrogen fertilizer loading (p-value = 0.012); (2) percent cropland-pasture ($p < 0.001$); (3) natural log of population density ($p < 0.001$); (4) percent well-drained soils ($p = 0.002$); (5) depth to the seasonally high water table ($p = 0.001$); and (6) presence or absence of a fracture zone within an aquifer ($p = 0.002$). Variables 1-3 were compiled within circular, 500 in radius areas surrounding sampled wells, and variables 4-6 were compiled within larger areas representing targeted land use and aquifers of interest. Fitting criteria indicate that the full logistic-regression model is highly significant ($p < 0.001$), compared with an intercept-only model that contains none of the explanatory variables. A goodness-of-fit test indicates that the model fits the data well, and observed and predicted probabilities of exceeding 4 mg/L nitrate in ground water are strongly correlated (r2 = 0.971). Based on the multivariate LR model, vulnerability of ground water to contamination by nitrate depends not on any single factor but on the combined, simultaneous influence of factors representing nitrogen loading sources and aquifer susceptibility characteristics.

Parker, W.F. and B.J. Mee. 1982. Survival of *Salmonella Adelaide* and Fecal Coliforms in Coarse Sands of the Swan Coastal Plain, Western Australia. Applied and Environmental Microbiology. 43(5):981-986.

The survival of "Salmonella adelaide" and fecal coliforms in two coarse sands influenced by two sources of septic tank effluent was studied. The experiments were conducted in conditions that reflected the soil environment beneath functioning septic tank systems. Significant differences in survival were found with different effluent sources. In one experiment the survival of "Salmonella adelaide" was similar to that of fecal coliforms; in the other it was not. The nonuniform, multiphasic nature of survival curves and variability observed in these experiments suggests that the application of such survival data for establishing management criteria for septic tank systems - by, for example, the use of soil moisture characteristic curves to give estimates of movement in the soil - is inappropriate.

Pedersen, J.K. P.L. Bjerg, and T.H. Christensen. 1991. Correlation of Nitrate Profiles with Groundwater and Sediment Chacteristics in a Shallow Sandy Aquifer. J. Hydrol. 124:263-277.

Pell, Mikael., Fred Nyberg, and Hans Ljunggren. 1990. Microbial Numbers and Activity During Infiltration of Septic-tank Effluent in a Subsurface Sand Filter. Water Research. 24(11):1347-1354.

A subsurface, 4-person sand-filter system for treating septic-tank effluent was subjected to conventional water analysis and to an extended microbial analysis of the filter material. Measured rates of CO sub(2) production in the filter material suggest that the system has a good microbial capacity to degrade the organic matter in wastewater; the volume effectively treated depends on the BOD (e.g. 951 m super(-2) day super(-1) at a BOD of 169 mg 1 super(-1) and 285 1 m super(-2) at a BOD of 74 mg 1 super(-1)). The actual load was 40 to 80 1 m super(-2) day super(-1). Based on viable counts of bacteria the amounts of P and N bound in the 13 plus or minus 10 g dw m super(-2) viable biomass were calculated to correspond to the amounts produced by 1 person in <2 days. From the ATP levels in the sand, the active biomass was calculated to be 19 plus or minus 15 g dw m super(-2), indicating that the viable biomass also gives an accurate estimate of the active biomass. The levels of ATP in the sand-filter surface revealed that the loading of wastewater occurred unevenly. The high numbers of ammonium-oxidizing bacteria (4 x 10 super(5)-6 x 10 super(6) g super(-1) dw) and denitrifying bacteria (2 x 10 super(7)-1 x 10 super(9) g super(-1) dw) in the surface layer show that the system was predominantly operating aerobically and had a high potential for removing nitrogen. The microbial techniques used were sensitive enough to detect the decrease in biomass that occurred with increasing depth.

Perkins, Richard J. 1984. Septic Tanks, Lot Size and Pollution of Water Table Aquifers. Journal of Environmental Health, 46(6): 298-304.

As the pollution potential of septic systems becomes more widely recognized, and as pollution by septic systems becomes more wide-spread, pressure to develop and implement rational and effective standards will increase. At present, there is no uniform approach among regulatory agencies to setting standards. Past experience suggests that regulation of septic tank density is an effective means of minimizing pollution potential, and that regulation of penetration depth of wells into ground water and of separation distance between wells and drainfields are insufficient preventive measures when used alone. Density of septic systems is regulated through minimum lot size requirements. The range of lot sizes which provides a minimum reasonable protection of groundwater quality appears to be from 0.2 to 0.4 hectare based on reported data, and from 0.3 to 0.4 ha, based on theory.

Peterson, T.C. and R.C. Ward. 1987. Impact of Adverse Hydrological Events on Bacterial Translocation in Coarse Soils Near On-site Wastewater Treatment Systems. In On-Site Wastewater Treatment: Proceedings of the Fifth National Symposium On Individual and Small Community Sewage Systems. American Society of Agricultural Engineers (ASAE). St. Joseph, MI. p. 87-93.

A mathematical bacterial transport model showed that, under adverse hydrological conditions, enteric coliform bacteria are likely to travel beyond the arbitrary 1.2 m (4 ft) of minimum required depth when dealing with coarse grained soils for on-site system approval. Amount of fines and organic matter are cited as improving bacterial retention. Further analysis of particle size class and organic matter content included with the commonly used percolation test is suggested.

Peterson, T.C. and R.C. Ward. 1989. Bacterial; Retention in Soils. New Perspectives, New Recommendations. Journal of Environmental Health, 51(4): 196-200.

Peterson, T.C. and R.C. Ward. 1989. Development of a Bacterial Transport Model for Coarse Soils. Water Sources Bulletin. 25(2):349-357.

A bacterial transport model, developed to analyze bacterial translocation in coarse-grained soils, is presented. The complex governing equation is presented first, followed by analyses of each of the major processes influencing bacterial transport. These analyses suggest simplification of the governing equation is feasible when input data on specific processes are limited or unavailable. Model parameters, including bacterial die-off, bacterial distribution, input bacterial concentration, and saturated hydraulic conductivity, were randomly generated using a procedure known to produce either a normal or log-normal distribution of random numbers. Monte Carlo simulations were completed, and the resulting output was used to generate cumulative frequency distributions showing the probability of bacterial transport beyond various soil depths.

Pieper, A.P., J.N. Ryan, R.W. Harvey, G.L. Amy, T.H. Illangasekare, and D.W. Metge. 1997. Transport and Recovery of Bacteriophage PRD1 in a Sand and Gravel Aquifer: Effect of Sewage-Derived Organic Matter. Environmental Science and Technology 31, 1163-1170.

Postma, D., C. Bosen, H. Kristiansen, and F. Larsen. 1991. Nitrate Reduction in an Unconfined Sandy Aquifer: Water Chemistry, Reduction Processes, and Geochemical Modeling. Water Resource Research. 27:2027-2045.

Postma, Frank B., A.J. Gold, and G. W. Loomis. 1992. Nutrient and Microbial Movement from Seasonally-Used Septic Systems. 1992. Journal of Environmental Health, 52(2): 5-10.

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 6m 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.

Powelson, D.K., J.R. Simpson, and C.P. Gebra. 1990. Virus transport and Survival in Saturated and Unsaturated Flow Through Soil Column. Journal of Environmental Quality. 19:396-401.

Powelson David K., James R. Simpson, and Charles P. Gerba. 1991. Effects of Organic Matter on Virus Transport in Unsaturated Flow. Applied and Environmental Microbiology. 57(8)2192-2196.

Powelson, D.K. C.P Gerba, and M.T. Yahya. 1993. Virus Transport and Removal in Wastewater During Aquifer Recharge. Water Research, 27(4):583.590.

Powelson David K. and Charles P. Gerba. 1994. Virus Removal from Effluent During Saturated and Unsaturated Flow Through Soil Columns. Water Research. 28(10):2175-2181.

Prins, C.J. and K.W. Lustig. 1988. Innovative Septic System Management. J. Water Pollut. Control Fed. 60:614-620.

Summarized is an informative introduction of the Panhandle Health District (PHD), in the northern panhandle of Idaho, and its innovative septic system management program for groundwater protection. Presented are the reason for the PHD's establishment and the different aspects of its management plan. Basic discussion of the PHD's regulations, its public education program and the success it has brought about is summarized in a journalistic type format.

Quan, E.L., H.R. Sweet, and Joseph R. Illian. 1974. Subsurface Sewage Disposal and Contamination of Ground Water in East Portland, Oregon. Ground Water. 12(6):356-367.

This report describes the geology, hydrology and hydrogeology in a 30 sq. mi. unsewered area in Multnomah County, Oregon. Subsurface disposal of domestic waste from cesspools, seepage beds and drainage fields in this area has contaminated the groundwater and has affected the quality of surface water in an adjacent area downgradient from the unsewered area. Nitrate levels (4.7 to 11.86 mg/1) were present in wells which tap the upper portions of the saturated zone in the unsewered areas.

Reneau, R.B. Jr., C. Hagedorn, and M.J. Degen. 1989. Fate and transport of Biological and Inorganic Contaminants from On-Site Disposal of Domestic Wastewater. J. Environmental Quality 18(2):135-144.

An on-site wastewater disposal system (OSWDS) is the primary method for domestic waste disposal in sparsely populated areas and in numerous suburban counties. The most common OSWDS is a septic tank with a subsurface soil absorption system that relies on gravity to move wastewater from the residence to the soil with minimal pretreatment of waste before application to the soil. Much of the renovation occurs as the wastewater percolates through the soil prior to reaching ground or surface waters. In 1980, 20.9 million residences (24.1% of the total in the USA) applied approximately 14 X 10^9 L of domestic wastewater to U.S. soils each day. These numbers emphasize the need for assessing the effect of OSWDS on the quality of the environment. This review addresses the potential impact of selected biological and chemical contaminants present in domestic wastewater on environmental quality. Inefficient use of a soil's renovative capacity (primarily because of poor effluent distribution) can result in extensive travel distances for biological or chemical contaminants as well as hydraulic failure of the OSWDS. The need for further investigation of the potential for water contamination from nitrogenous components and possible mechanisms to reduce the degradation potential of N is addressed. Most studies assume that the dynamics of viral translocation through soil resemble those of fecal bacteria. This assumption may not be correct. Lastly, a critical examination of fate of N, viruses, and fecal bacteria introduced into soils via alternative OSWDS and modified conventional OSWDS should be a priority research initiative.

Robertson, W.D. and D.W. Blowes. 1995. Major Ion and Trace Metal Geochemistry of an Acidic Septic System Plume in Silt. Ground Water. 33(2):275-283.

> Four years of detailed groundwater monitoring at a newly-installed, seasonal-use, domestic septic system located on poorly-buffered (CaCO3 equivalent content less than/equal to 1.6%) lacustrine silt, reveal the development of an acidic groundwater plume. Acid, generated by oxidation of effluent NH4+ and dissolved organic carbon (DOC) and possibly sulfide minerals present in the sediment, has resulted in a distal plume core zone with pH values in the range of 4.4 to 5.0. The acidic zone, is anaerobic based on persistence of NH4+ (>2mg/L, as N) and DOC (> 10 mg/L) and is associated with high average concentrations of the trace metals Fe (4.7 mg/L), A1 (1.9 mg/L), Mn (3.6 mg/L), Ni (0.4 mg/L), and Cr (0.2 mg/L). Attenuation of N along the plume value of 0.5 after 4 m of subsurface flow. Increased SO4^2- levels observed in the zone of N depletion suggest that attenuation can be at least partly attributed to reduction of plume NO3- by oxidation of reduced S present in the sediment. PO4^3- has not migrated beyond the tile bed gravel layer demonstrating that PO4^3- mobility is limited in these sediments (retardation factor > 10). Several simple suggestions are made for modifying septic system design in such environments to achieve improved effluent oxidation and acidity neutralization.

Robertson, W. D., J. A. Cherry, and E. A. Sudicky. 1991. Groundwater Contamination From Two Small Septic Systems On Sand Aquifers. Ground Water. 29(1):82-92.

> Distinct plumes of septic system impacted ground water at two single family homes located on shallow unconfined sand aquifers in Ontario showed elevated levels of Cl-, No3-, Na+, Ca^2+, K+, alkalinity, and dissolved organic carbon and depressed levels of pH and dissolved oxygen. At the Cambridge site the plume had sharp lateral and vertical boundaries and was more than 130 m in length with a uniform width of about 10 m. As a result of low transverse dispersion in the aquifer, mobile plume solutes such as NO3- and Na+ occurred at more than 50 percent of the source concentrations 130 m downgradient from the septic system. At the Muskoka site the plume also had discrete boundaries reflecting low transverse dispersion. After 1.5 years of system operation, the Muskoka plume began discharging to a river located 20 m from the tile field. Almost complete NO3- attenuation was observed within the last 2 m of the plume flowpath before discharge to the river. This was attributed to denitrification occurring within organic matter-enriched riverbed sediments. The very weakly dispersive nature of the two aquifers was consistent with the results of recently reported natural-gradient tracer tests in sands. Therefore, for many unconfined sand aquifers, the minimum distance to well regulations for permitting septic systems in most parts of North America should not be expected to be adequately protective of well-water quality in situations where mobile contaminants such as NO3- are not attenuated by chemical or microbiological processes.

Robertson, W.D. and J. Harman. 1999. Phosphate Plume Persistence at Two Decommissioned Septic System Sites. Ground Water. 37(2):228-236.

> Long-term monitoring of two well-characterized, oxidizing septic system plumes (Langton and Long Point 2 sites) over periods extending two to four years after decommissioning, has revealed that ground water PO sub(4) super(3-) concentrations (0.4 to 5 mg/L P) have persisted at levels virtually unchanged from those observed during active sewage loading. In addition, the frontal part of the PO sub(4) super(3-) plume at the Long Point 2 site can be observed to continue to advance during the decommissioned period. At the Langton site, where an active regional ground water flow system is present, all major plume solutes (Na super(+), Ca super(2+), Cl super(-), NO sub(3) super(-)) returned to background values within one year of decommissioning, with the exception of PO sub(4) super(3-). This evidence suggests that phosphate behavior in the ground water zone at these sites is dominated by sorption reactions that are both rapid and reversible. Thus, if septic system phosphorus is not retained in the vadose zone, but is transported into the ground water zone, it has the potential to be persistent and to be mobile enough to constitute a threat to downgradient surface water environments. This evidence also shows that when a septic system is decommissioned, if an oxidizing PO sub(4) super(3-) plume is present, downgradient P loading is not likely to diminish for many years thereafter.

Robertson, W.D., S.L. Schiff, and C.J. Ptacek. 1998. Review of Phosphate Mobility and Persistence in 10 Septic System Plumes. Ground Water. 36(6):1000-1010.

Phosphate distribution was reviewed in 10 mature, highly monitored septic system ground water plumes in central Canada. It was shown that six plumes (primarily those on calcareous sands) of enriched P concentrations (0.5 to 5 mg/L P) exceeding 10 m in length are present. In each case, phosphate migration velocity is highly retarded (retardation factor, 20 to 100) compared to the ground water velocity, but migration rates remain sufficiently fast (similar to 1 m/a) to be of concern when considering long-term operation and the normal setback distance of septic systems from adjacent surface water bodies (similar to 15 m). Much smaller scale phosphate plumes (< 3 m in length) are present at the acidic sites on noncalcareous sands and on silt- and clay-rich sediments. At all of the sites, ground water concentrations are lower than effluent values by amounts ranging from 23 to 99%, suggesting that P accumulation has occurred in the vadose zone. This was confirmed by sediment analyses at four of the sites which, in each case, showed that zones of P enrichment were present within 1 m of the infiltration pipes (Wood 1993; Zanini et al. 1998). Also, observed phosphate concentrations are generally consistent with values expected based on the solubility constraints of the minerals vivianite in reducing zones (including the septic tank), and strengite and variscite in oxidizing zones, providing further evidence that mineral precipitation reactions play a role in limiting P concentrations. Strengite and variscite have the potential to limit P to low concentrations (<0.1 mg/L) under acidic conditions, but oxidation of sewage effluent leads to acidic conditions only in noncalcareous terrain or beneath old septic systems where calcium carbonate has been depleted. Overall, phosphate plume migration velocities in ground water appear to be controlled by sorption processes, but the phosphate concentrations that are present in the plumes appear to be strongly controlled by mineral precipitation reactions that occur in close proximity to the infiltration pipes.

Rutledge, E.M., C.R. Mote, M.S. Hirsch, H.D. Scott, and D.T. Mitchell. Disposal of Household Wastewater to Soils of High Stone Content (1977-1980). Arkansas Water Resources Center, University of Arkansas, Fayetteville, AR. Publication No. 99.

Rutledge, E.M., C.R. Mote, D.T. Mitchell, M.S. Hirsch, M.D. Harper, H.D. Scott, and C.L. Griffis. Disposal of Household Wastewater to Soils of High Stone Content (1981-1983). Arkansas Water Resources Center, University of Arkansas, Fayetteville, AR. Publication No. 103.

Ryker, Sarah J. and Joseph L. Jones. 1995. Nitrate Concentration in Ground water of the Central Columbia Plateau. USGS Open-File Report 95-445, last modified Jan., 1998.

Scandura, J.E. and M.D. Sobsey. 1997. Viral and Bacterial Contamination of Groundwater from On-site Sewage Treatment Systems. Water Science & Technology. 35(11/12):141-146.

On-site septic tank-soil absorption systems treating domestic wastewater have contaminated groundwaters with enteric viruses and other pathogens and caused drinking waterborne outbreaks. The factors influencing pathogen transport, survival and fate at on-site wastewater treatment systems remain inadequately characterized. We studied the survival and transport of a model enterovirus (BE-1) and faecal coliform bacteria in four on-site wastewater treatment systems (three conventional and one low pressure, small pipe diameter, pumped system) located in sandy soils typical of the coastal plains. Septic system wastewaters were seeded seasonally with known amounts of BE-1 and the fate of BE-1, faecal coliforms and other wastewater constituents were followed for three months in seeded wastewaters and groundwaters of drainfield monitoring wells. BE-1 levels in seeded wastewaters declined exponentially by kinetics consistent with a 3d hydraulic residence time. BE-1 was detected in ground waters of monitoring wells as early as 1d after seeding and persisted up to two months. Virus detection in ground water was greater in winter than in summer and was positively associated with proximity to septic effluent distribution lines, drainfield soils with the lowest clay content, elevated ground water pH and shallower vadose zones. Viruses were not strongly associated with either distance from septic tank or faecal coliform levels in groundwater. Under optimum conditions, virus reductions were as high as 9 log sub(10), but in systems with the most coarse (sand) soils and highest water tables (most shallow vadose zones), there was extensive ground water contamination by viruses and other wastewater constituents. Under some conditions, septic systems in sandy coastal plains soils can contaminate ground water with viruses and other wastewater constituents.

Schaub, S.A. and C.A. Sorber. 1977. Virus and Bacteria Removal from Wastewater by Rapid Infiltration Through Soil. Applied and Environmental Microbiology. 33:609-619.

Schudel, Paul and Markus Boller. 1990. Onsite Water treatment With Intermittent Buried Filters. Water Science and Technology. 22(3/4):93-100.

A few intermittent buried sand filters have been constructed in Switzerland for the on-site treatment of small wastewater sources. The good experiences to date will certainly favor a more frequent application in the future. Investigations of the hydraulic behavior and the removal efficiency, especially in one filter during and after a hydraulic flush, showed that the hydraulic load per dosing interval should preferably not be larger than 10 l/m^2, interval. Tracer experiments as well as the analysis of pollutants during the intervals revealed considerable quality fluctuations along the hydraulic peak discharge depending strongly on the instantaneous hydraulic dose. Furthermore, maturation periods of several months are necessary in order to reach a maximum steady state performance that usually includes full nitrification. Besides detailed information on the hydraulic behavior, a series of performance data of different buried filters gives an overview of the concentrations and the removal rates observed for organic matter and nitrogen compounds.

Schwager, Andreas and Markus Boller. 1997. Transport Phenomena in Intermittent Filters. Water Science and Technology. 35(6):13-20.

Siegrist, R.L. and W.C. Boyle. 1982. Onsite Reclamation of Residential Greywater. In On-Site Wastewater Treatment: Proceedings of the Third National Symposium On Individual and Small Community Sewage Systems. American Society of Agricultural Engineers (ASAE). St. Joseph, MI. p. 176-186.

Summarizes a field study of four household greywater septic tank/sand filter treatment systems. Defines greywater generation and characteristics along with the performance of two sand filter runs operated under two dosing schemes and different textured sand column operated under different loading rates. Results characterize greywater stability and the impact of high loading rates and high frequency dosing on performance and filter run times.

Shaw, B. and N.B. Turyk. 1994. Nitrate-N Loading to Ground water from Pressurized Mound, In-ground and At Grade Septic Systems. In On-Site Wastewater Treatment: Proceedings of the Seventh National Symposium On Individual and Small Community Sewage Systems. American Society of Agricultural Engineers (ASAE). St. Joseph, MI. p. 504-513.

Fourteen pressure dosed septic drainfields in sandy soil areas of Wisconsin were studied to evaluate their impact on groundwater quality. They included; one single family at grade system, two single family and four multiple family in ground pressure systems, and four single family and three multiple family mound systems. Dosing chamber effluent was sampled 10 times during the 18 month study, and the total volume of effluent pumped to the drainfield was measured. Groundwater sampling was conducted quarterly from two multiport well nests of four wells each. These well nests were located in the contaminant plume downgradient of each drainfield. Analyses performed on the groundwater samples included; nitrate-N (NO_2+NO_3-N), ammonium (NH_4-N), Total Kjeldahl-N, chloride, pH, conductivity, total phosphorus, total hardness, and alkalinity. Biochemical oxygen demand (BOD) and chemical oxygen demand (COD) were run on some sample sets. All 14 systems resulted in groundwater nitrate-N exceeding the drinking water standard of 10 mg/L. Values ranged from 21 to 108 mg/L in the contaminant plumes, and averaged 34 mg/l for single family systems and 31 mg/l for multiple family systems. Nitrogen to chloride ratios for dosing chambers and groundwater were used to evaluate nitrogen loss from drainfields. These ratios indicate there was no significant nitrogen loss occurring from the drainfields by denitrification or volatilization. The concentration ratio of nitrogen and chloride in groundwater contamination plumes compared to dosing chambers was used as an index of dilution of wastewater by upgradient groundwater or groundwater recharge in the vicinity of the drainfield. This indicates that a significant degree of dilution is occurring between the outlet pipe from the dosing chamber and the contaminant plume, within about 6 m of the drainfield. The average ratio of nitrogen concentrations in effluent to nitrogen concentrations in groundwater wad 2.4, and ranged from 1.3 to 3.8. Hydraulic loading, drainfield orientation to groundwater flow, and groundwater flow characteristics all influence the amount of dilution that occurs as effluent enters and mixes with groundwater. The systems that were evaluated all treated wastewater as designed for bacterial removal, but did little for removal of nitrate-N from wastewater.

Sinton, L.W. 1986. Microbial Contamination of Alluvial Gravel Aquifers by Septic Tank Effluent. Water, Air, and Soil Pollution, 28(3/4):407-425.

The effects of two methods of septic tank effluent disposal on the microbial quality of alluvial gravel aquifers were investigated at an experimental site in the Canterbury Plains, New Zealand. The movement of fecal coliform bacteria 9 m from a 5.5 m deep soakage pit into an unconfined aquifer, and 42 m from an 18 m deep injection bore into a confined aquifer was recorded. Partial sealing of the soakage pit sidewalls was evident, but approximately 80% of the effluent appeared to percolate rapidly into the unconfined groundwater through a permeable pathway in the unsaturated zone. There was evidence of groundwater mounding beneath the soakage pit and around the injection bore and the consequent radial spread of leachate from both disposal structures. In both the confined and unconfined aquifers, the most heavily contaminated bores exhibited marked diurnal fluctuations in fecal coliform concentrations in response to periods of effluent discharge. Implications of the findings for the monitoring and management of groundwater quality beneath unsewered communities on alluvial gravel formations are briefly discussed.

Smith, M.S., G.W. Thomas, R.E. White, and D. Ritonga. 1985. Transport of *Escherichia coli* Through Intact and Disturbed Soil Columns. Journal of Environmental Quality. 14(1):87-91.

Spalding, Roy F, M.E. Exner, C.W. Lindau, and D.W. Eaton. 1982. Investigation of Sources of Groundwater Nitrate Contamination in the Burbank -Wallula Area of Washington. U.S.A. J. Hydrology. 58:307-228.

Starr J.L. and B.L. Sawhney. 1980. Movement of Nitrogen and Carbon from a Septic System Drainfield. Water, Air, and Soil Pollution. 13:113-123.

Starr R.C. and R.W. Gillham. 1993. Denitrification and Organic Carbon Availability in Two Aquifers. Ground Water. 31:934-947.

Steinheimer, Thomas, R. and Scoggin, Kenwood D. 1998. Environmental Science and Technology. 32(8):1048-1052.

Stevik, Tor Kristian, Geir Ausland, Petter Deinboll Jenssen, Robert L. Siegrist. 1999. Removal of *E. coli* During Intermittent Filtration of Wastewater Effluent as Affected by Dosing Rate and Media Type. Water Research. 33(9):2088-2098.

Wastewater effluent dosing rates of 25 and 50 mm/day were intermittently applied in eight daily doses of 3.125 or 6.25 mm each, to 15-cm diameter 80 cm high columns packed with two types of Light Weight Aggregates (LWA) and one type of activated carbon aggregates. After three months of wastewater effluent application at 25 mm/day to stabilize the filter systems, Escherichia coli was spiked once each day onto the surface of the columns and wastewater effluent was applied at 25 mm/day for the months. The same procedure was repeated for effluent application rate 50 mm/day. During operation, hydraulic behavior was moni**tor**ed by moisture tensiometers located 5, 10, 20 and 40 cm below the filter surface as well as by radiotracer studies. Removal behavior was assessed by sampling and analysis of the column percolate and media within the column. The removal of E. coli was decreased as a result of increasing the dosing rate for all three media. In all media, the highest removal rates were observed in the upper part of the columns. Sorption head measurements showed that each effluent dose rapidly penetrates through the upper part of the filters, until a steady state, unsaturated flow was established in the lower sections. Different flow patterns were observed for the two dosing rates. For the dosing rate of 50 mm/day, the flow was penetrating faster, and to a deeper level before establishing steady unsaturated flow. Fast flow through the upper part of the filter, where the bacterial removal is most effective, may explain the significantly lower removal for the dosing rate of 50 mm/day. The dynamic behavior of the filter columns showed that most of the water movement took place right after dose application, during intermittent dosing. This indicates that dose size may be just as important for bacterial removal as the daily dosing rate.

Stevik, T.K., G. Ausland, J.F. Hanssen, and P.D. Jenssen. 1999. The Influence of Physical and Chemical Factors on the Transport of *E. coli* Through Biological Filters for Wastewater Purification. Water Research. 33(18):3701-3706.

Transport studies of Escherichia coli were performed in laboratory columns over a period of 15 months. The effects of the filter media properties, effective grain size, specific surface area, pH and cation exchange capacity were examined for loading rates of 25 mm and 50 mm/day applied as 8 doses per day. Distilled water and two solutions of ionic strength 0.00725 and 0.097 M were applied to the columns. Physical factors were found to be the most important for the removal of E. coli. Reduced grain size, hydraulic loading rate and increased specific surface area of the grains significantly reduced transport of E. coli. Chemical factors such as pH, cation exchange capacity and wastewater ionic strength showed less significant effects. The results indicate that the chemical factors in biological wastewater filters have a minor influence on the removal of E. coli after a stabilizing period of three months. Minimum hydraulic retention time (time required for 10% breakthrough of a conservative tracer) was found to be the most relevant parameter for predicting bacterial removal in unsaturated filter systems. Correlation between observed data and a first order removal model, based on minimum retention time, was 0.70.

Stuart, M.A., F.J. Rich, and G.A. Bishop. 1995. Survey of Nitrate Contamination in Shallow Domestic Drinking Water Wells of the Inner Coastal Plain of Georgia. Ground Water 33(2):283-290.

Tare Vinod, and S.D. Bokil. 1982. Wastewater Treatment by Soils: Role of Particle-Size Distribution. Journal of Environmental Quality 11(4):596-602.

Tesoriero, A.J. and Frank D. Voss. 1997. Predicting the Probability of Elevated Nitrate Concentrations in the Puget Sound Basin: Implications for Aquifer Susceptibility and Vulnerability. Ground Water. 35(6):1029-1039.

The occurrence and distribution of elevated nitrate concentrations (greater than or equal to 3 mg/l) in ground water in the Puget Sound Basin, Washington, were determined by examining existing data from more than 3000 wells. Models that estimate the probability that a well has an elevated nitrate concentration were constructed by relating the occurrence of elevated nitrate concentrations to both natural and anthropogenic variables using logistic regression. The variables that best explain the occurrence of elevated nitrate concentrations were well depth, surficial geology, and the percentage of urban and agricultural land within a radius of 3.2 kilometers of the well. From these relations, logistic regression models were developed to assess aquifer susceptibility (relative ease with which contaminants will reach aquifer) and ground-water vulnerability (relative ease with which contaminants will reach aquifer for a given set of land-use practices). Both models performed well at predicting the probability of elevated nitrate concentrations in an independent data set. This approach to assessing aquifer susceptibility and ground-water vulnerability has the advantages of having both model variables and coefficient values determined on the basis of existing water quality information and does not depend on the assignment of variables and weighting factors based on qualitative criteria.

Thomas, Grant W. and Ronald E. Phillips. 1979. Consequences of Water Movement in Macropores. Journal of Environmental Quality. 8(2):149-152.

Current views of infiltration of water into soils are based on nearly complete displacement of soil by incoming water. In general, rapid flow down macropores and its effect on water and solute distribution have not been considered very important by the majority of researchers. Evidence is presented to show that flow of water through macropores is important in soil and ground water recharge and in salt movement through soils.

Van Cuyk, S., R.L. Siegrist, A. Logan, S. Masson, E. Fischer and L. Figueroa. 2001. Hydraulic and Purification Behaviors and Their Interactions During Wastewater Treatment in Soil Infiltration Systems. Water Research. 35(4): 953-964.

Four three-dimensional lysimeters were established in a pilot laboratory with the same medium sand and either an aggregate-laden (AL) or aggregate-free (AF) infiltration surface and a 60- or 90-cm soil vadose zone depth to depth to ground water. During 48 weeks of operation, each lysimeter was dosed 4 times daily with septic tank effluent (STE) at 5 cm/d (AL) or 8.4 cm/d (AF). Weekly monitoring was done to characterize the STE, percolate flow and composition, water content distribution within the lysimeters. Bromide tracer tests were completed at weeks 0, 8, and 45 and during the latter two times, ice nucleating active (INA) bacteria and MS-2 and PRD-1 bacteriophages were used as bacterial and viral surrogates. After 48 weeks, soil cores were collected and analyzed for chemical and microbial properties. The observations made during this study revealed a dynamic, interactive behavior for hydraulic and purification process that were similar for all four lysimeters. Media utilization and bromide retention times increased during the first two months of operation with the median bromide breakthrough exceeding one day at start-up and increasing to two days or more. Purification process were gradually established over four months or longer, after which there were high removal efficiencies (>90%) for organic constituents, microorganisms, and virus, but only limited removal of nutrients. Soil core analyses revealed high biogeochemical activity with the infiltrative zone from 0 to 15cm depth. All four lysimeters exhibited comparable behavior and there were no significant differences in performance attributable to infiltrative surface character or soil depth. It is speculated that the comparable performance is due to a similar and sufficient degree of soil clogging genesis coupled with bioprocesses that effectively purified the wastewater effluent given the adequate retention times and high volumetric utilization's of the sand media.

Van Cuyk, Sheila, Robert L. Siegrist, and Andy J. Logan. 2001. Evaluation of Virus and Microbial Purification in Wastewater Soil Absorption Systems Using Multicomponent Surrogate and Tracer Addition. In On-Site Wastewater Treatment: Proceedings of the Ninth International Symposium On Individual and Small Community Sewage Systems. American Society of Agricultural Engineers (ASAE). St. Joseph, MI. p. 30-40.

Wastewater soil absorption systems (WSAS) have the potential to achieve high treatment efficiencies, yet the understanding and predictability of performance with respect to removal of virus and other pathogens remains limited. As part of a long-term program of research to elucidate the fundamental relationships between performance and WSAS process design and environmental conditions, research has been completed to evaluate virus and microbial purification using multicomponent surrogate and tracer addition. The primary goal of this research was to quantify the removal of virus and bacteria through the use of microbial surrogates and conservative tracers during controlled experiments with 3-D lysimeters in the laboratory and testing of mature WSAS under field conditions. The surrogates and tracers employed to date have included two viruses (MS-2 and PRD-1 bacteriophages), one bacterium (ice-nucleating active (INA) Pseudomonas), and one conservative tracer (bromide ion). In addition, efforts have been made to determine the relationship between virus and fecal coliforms in soil samples below a WSAS, and the correlation between E. coli. concentrations measured in percolating soil solution as compared to those estimated from analyses of soil solids samples. The results of the research completed to date have revealed that episodic breakthrough of virus and bacteria does occur in WSAS, particularly during early operation, but that a 3-log removal of virus and near complete removal of fecal bacteria can reasonably be expected in WSAS with 60 to 90 cm of sandy medium. Additionally, results from the research indicate that fecal coliforms may be indicative of virus in soil media directly beneath WSAS receiving STE and the concentrations of fecal coliforms in percolating soil solution may be conservatively estimated from analysis of soil solids. Further laboratory and field research is continuing.

Vanlandingham David S. and Mark A. Gross. 1998. Contaminant Distribution in Intermittent Sand Filters. In On-Site Wastewater Treatment: Proceedings of the Eighth National Symposium On Individual and Small Community Sewage Systems. American Society of Agricultural Engineers (ASAE). St. Joseph, MI. p. 380-387.

Vaughn, J.M., E.F. Landry, and M.Z. Thomas. 1983. Entrainment of Viruses from Septic Tank Leach Fields Through a Shallow, Sandy Soil Aquifer. Applied and Environmental Microbiology. 45(5):l474-480.

A study was conducted to focus on the movement of human enteroviruses from a subsurface wastewater disposal system through a shallow aquifer. Virus particles were recovered at down-gradient distances of 67.05m and from aquifer depths of l8 m. A negative correlation was observed between virus occurrence and distance from the wastewater source. Virus occurrence is discussed in relation to distance, pH, conductivity, coliforms and season. Virus occurrence could not be statistically correlated with coliforms indicating limitations of current microbial water quality indicators for predicting virological quality of groundwater.

Ver Hey, M.E. and W.W. Woessner. 1987. Documentation of the Degree of Waste Treatment Provided by Septic Systems, Vadose Zone and Aquifer In Intermontane Soils Underlain by Sand and Gravel. In On-Site Wastewater Treatment: Proceedings of the Fifth National Symposium On Individual and Small Community Sewage Systems. American Society of Agricultural Engineers (ASAE). St. Joseph, MI. p. 77-86.

Focus of this study lies in documenting the effectiveness of the septic tank, drainfield, vadose zone, and the groundwater system in treating septic system wastes that are applied to the coarse soils of the northwestern alluvial valleys. It was found that the traditional septic system design is ineffective in treating domestic wastes in these soils. Reason given are lack of appreciable retention time, large interstitial pore spaces, minimal exchange sites below the drainfield, coliforms found in all down gradient wells, and the fact that only a small portion of the drainfield area is used for effluent treatment.

Walker, W.G., J. Bouma, J., D.R. Kenney, and P.G. Olcott. 1973. Nitrogen Transformations During Subsurface Disposal of Septic Tank Effluent in Sands: II. Ground Water Quality. Journal of Environmental Quality. 2(4):521-525.

Groundwater observation wells were installed in the immediate vicinity of four septic tank effluent soil disposal systems. Potentiometric maps were constructed from measurements of the groundwater level at each site to establish the direction of movement. Groundwater samples were pumped from each well to establish patterns of N enrichment in the ground water around the seepage beds and to evaluate the performance of these disposal systems in sands in terms of nitrogen removal. Soil disposal systems of septic tank effluent in sands were found to add significant quantities of nitrate to underlying groundwater. The data obtained suggest that in sands, the only active mechanism of lowering the nitrate content is by dilution with uncontaminated groundwater.

Whelan, B.R. 1988. Disposal of Septic Tank Effluent in Calcareous Sands. Journal of Environmental Quality. 17(2):272-277.

Perth, Western Australia, has 430,000 households with septic tanks discharging through sandy soils into the groundwater, which is pumped for domestic irrigation and public water supply. This study investigated the suitability of calcareous sands (Xeropsamment), one of Perth's major soil types, for treatment of septic tank effluent. Calcareous sands adjacent and below two septic tank systems were sampled to a depth of 8 m and the soil pH, soil N, and soil P contents were measured.

Whelan, B.R. and N. J. Barrow. 1984a The Movement of Septic Tank Effluent through Sandy Soils near Perth. I Movement of Nitrogen. Aust. J. Soil Res, 22:283-292.

Whelan, B.R. and N. J. Barrow. 1984b. The Movement of Septic Tank Effluent through Sandy Soils near Perth. II Movement of Phosphorus. Aust. J. Soil Res, 22:293-302.

Focus of this study lies in documenting the effectiveness of the septic tank, drainfield, vadose zone, and the groundwater system in treating septic system wastes that are applied to the coarse soils of the northwestern alluvial valleys. It was found that the traditional septic system design is ineffective in treating domestic wastes in these soils. Reason given are lack of appreciable retention time, large interstitial pore spaces, minimal exchange sites below the drainfield, coliforms found in all down gradient wells, and the fact that only a small portion of the drainfield area is used for effluent treatment. The potential of seven septic tank installations in the Perth (Western Australia) metropolitan area to contribute phosphate to the groundwater was investigated. The phosphate concentration in the soil solution below the soak wells and leach drains was measured using immiscible displacement and compared with the phosphate concentration of the water flowing into the systems. The phosphate sorbing properties of the subsoils were measured, and these were found to vary up to 100-fold within the same profile. A very strong correlation was established between a laboratory measure of the ability of the soil to sorb phosphate and the phosphate sorbed in the soil profile below leach drains and soak wells. The correlation held only for those systems for which little further phosphate was removed by reaction with the soil, and the phosphate in the soil solution was at or near the same concentration as the phosphate in the effluent. For a system receiving water from the bathroom, laundry and kitchen the phosphate concentration was as low as 8 ug P/ml. For a system receiving water from a toilet only, the concentration was as high as 29 ug P/m. In systems receiving water from both sources the values were intermediate. For systems that had been installed for more than a few years, the concentration of phosphorus in the soil water down to 6 m below the soak well and leach drain was similar to that in the effluent being discharged into the soil.

Wilhelm, S.R. and , S.L. Schiff, J.A. Cherry. 1994. Biogeochemical Evolution of Domestic Waste Water in Septic Systems: 1. Conceptual Model. Ground Water 32(6):905-916.

A conceptual model, developed by synthesizing the results of many researchers, which describes the geochemical evolution of domestic waste water in conventional on-site septic systems as the result of the interactions of a few major constituents, is presented. Individual on-site septic systems are used to dispose of approximately one-third of waste water in the US.

Wilhelm, Sheryl R., Sherry L. Schiff, and William D. Robertson. 1996. Biogeochemical Evolution of Domestic Waste Water in Septic Systems: 2 Application of Conceptual Model in Sandy Aquifers. Ground Water. 34(5):853-864.

Aqueous geochemical data from unconfined sand aquifers beneath two operating domestic septic systems are used to illustrate and evaluate a conceptual model of septic-system geochemistry. This model emphasizes the changing redox and alkalinity conditions in the septic system and the subsurface. The septic-tank effluents flow as distinct plumes downward through the unsaturated zones and then primarily laterally in the ground-water zones. The composition of the effluent was measured at several points in each system. At each site, the septic-tank effluent underwent aerobic oxidation in the unsaturated zone, which caused conversion of NH^+_4 to NO^-_3 , organic C to CO_2 and organic S to SO^{2-}_4. At the first site, calcium carbonate dissolution in the unsaturated zone buffered the acidity released by the redox reactions. In contrast, the second system was poorly buffered and the pH dropped from 6.7 to 4.9 as aerobic oxidation occurred. Below the water table a small amount of aerobic oxidation occurred at each site. Nitrate-N concentrations in the cores of both plumes were above 25 mg/l as the plumes traveled from the septic systems. At the second site, the ground-water plume discharges to a river at the edge of the property. As the effluent flowed through the organic C-rich sediments of the river bed, NO^-_3 disappeared and alkalinity increased, presumably due to denitrification. Differences in sediment composition at the two sites also led to different behaviors of Fe, Al, and possibly PO^{3-}_4 . The conceptual model offers an organized approach to interpreting the major geochemical trends observed in the two systems, which are determined mostly by the well-aerated unsaturated zones below the drain fields and the amount of buffering material present in the sediments.

Wilhelm, Sheryl R., Sherry L. Schiff, and William D. Robertson. 1994. Chemical Fate and Transport in a Domestic Septic System: Unsaturated and Saturated Zone Geochemistry. Environmental Toxicology and Chemistry. 13(2):193-203.

Monitoring the septic system at a single-family home provides quantitative information on geochemical evolution of septic-tank effluent along its travel path. In both the unsaturated and saturated (groundwater) zones, microbiological and chemical reactions occur that bring the effluent closer to equilibrium with the subsurface conditions. In the unsaturated zone, 90% of the DOC is removed from the effluent, mostly by aerobic oxidation, and NH^+_4 in the effluent is almost completely oxidized to NO^-_3 . As these reactions occur in the tile field, the oxygen content of the soil gas is partially depleted. Calcite dissolution from the soils in the unsaturated zone buffers the acidity of the oxidation reactions and increase Ca^{2+} concentrations. In the saturated zone, organic carbon oxidation in the effluent plume apparently decreases dissolved oxygen concentrations to < 1.0 mg/L. Potassium is retarded relative to other cations, and dissolved PO^{3-}_4 from the effluent is detectable in the ground water directly beneath the tile field but appears to be advancing very slowly, if at all, within the plume. In addition NO^-_3 concentrations remain above drinking-water standards (10 mg/L NO^-_3 -N) in the groundwater plume.

Williamson, A.K., M.D. Munn, S.J. Ryker, R.J. Wagner, J.C. Ebbert, and A.M. Vanderpool. 1998. Water Quality in the Central Columbia Plateau, Washington and Idaho, 1992-1995. U.S. Geological Survey Circular 1144, update March 3, 1998.

Woessner, W.W. and M.E. Ver Hey. 1987. Water Quality Management Options for a Coarse Alluvial Western Mountain Valley Aquifer Impacted by Septic System Wastes. In On-Site Wastewater Treatment: Proceedings of the Fifth National Symposium On Individual and Small Community Sewage Systems. American Society of Agricultural Engineers (ASAE). St. Joseph, MI. p. 329-337.

Four water quality management options for the western portion of the Missoula Valley, Montana are addressed in order to deal with septic tank waste impacts. Included options are to 1) accept current levels of aquifer water quality degradation and prevent further deterioration of potable supplies, 2) accept current levels of aquifer water quality and minimize further degradation, 3) reduce current levels of contamination, 4) allow for further aquifer water quality degradation and replace individual domestic water supplies with an alternative supply. The options are discussed and conclusions indicate that reducing current levels of contamination will provide the best long term water quality management scheme for the residents of Missoula Valley, MT.

Woessner, William W., Patrick N Ball, Dan C. DeBorde, and Thomas L Troy. 2001. Viral Transport in a Sand and Gravel Aquifer Under Field Pumping Conditions. Ground Water 39(6):886-894.

Ground water supplies contaminated with microbes cause more than 50% of the water-borne disease outbreaks in the United States. Proposed regulations suggest natural disinfection as a possible mechanism to treat microbe-impacted ground water under favorable conditions. However, the usefulness of current models employed to predict viral transport and natural attenuation rates is limited by the absence of field scale calibration data. At a remote floodplain aquifer in western Montana, the bacteriophages MS2, phiX174, and PRD1; attenuated poliovirus type-1 (CHAT strain); and bromide were seeded as a slug 21.5 m from a well pumping at a steady rate of 408 L/min. Over the 47-hour duration of the test, resulting in the exchange of 12 to 13 pore volumes, 77% of the bromide, 55 % of the PRD1, 17% of the MS2, 7 % of the phiX174, and 0.12 % of the poliovirus masses were recovered at the pumping well. Virus transport behavior was controlled by mechanical dispersion, preferential flow, time-dependent nonreversible and reversible attachment, and apparent mass transfer to immobile domains within the sand and gravel dominated aquifer. The percentage of virus recovery appears correlated with reported viral isoelectric point (pI) values. Successful modeling of viral transport in coarse-grained aquifers will require separation of viral specific properties from reported lumped viral-- transport system parameters.

WSDOH. 1994. Design Guideline for Conventional Gravity Distribution On-site Sewage Systems in Soil Type 1A. Environmental Health Programs.

Yates, M.V., C.P. Gerba, and L.M. Kelly. 1985. Virus Persistence in Groundwater. Applied and Environmental Microbiology. 49(4):778-781.

Yates, M.V. 1987. Septic Tank Siting to Minimize the Contamination of Ground Water by Microorganisms. Washington, D.C. U.S. EPA, Office of Ground-Water Protection, June 1987.

Ziebell, W.A.; J.L. Anderson, J. Bouma, and E.L. McCoy. 1975. Fecal Bacteria: Removal from Sewage by Soil. For Presentation at the 1975 Winter Meeting American Society of Agricultural Engineers. ASAE, St. Joseph, MI. Paper No. 75-2579.

Column experiments determined the fecal coliform removal capability of a sandy soil and a clayey soil. Results indicated that 60 cm of sandy soil will remove large numbers of fecal indicators and pathogens, but a deeper amount would be necessary for complete removal. Flow and temperature greatly affected the removal process. Sixty cm of clayey soil removed fecal indicators very effectively, but because of the less permeable nature and the characteristic air-filled soil pores, fecal coliforms could move through the soil without being removed and would later surface as an indicator of pollution. Tests were conducted on several variables. Both dosing and continuous flow studies were conducted. A lengthy list of references are provided with the article.