RULE DEVELOPMENT COMMITTEE ISSUE RESEARCH REPORT
- LOT SIZE (MINIMUM LAND AREA) -

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Topic & Issues:

Lot Size (Minimum Land Area)

QUESTIONS ASKED BY THE TRC

- Do we need to make changes in current lot size requirements?
- Where are we currently with minimum land area? What is the basis for the current requirements? What is included in lot size: land under surface water, road rights of way, steeply sloped area?
- Does minimum lot size pertain to new OSS or is it only for development of new lots?
- Should the definition of "development" be changed to distinguish between new lot development and new construction?
- Should minimum lot sizes be different for Type 1A soils?
- How does nitrate loading pertain to this topic?
- Can pretreatment to certain standards lead to reductions in minimum lot sizes?
- Should stacking of houses on side slopes be spoken to (re linear loading rates)?

ADDITIONAL QUESTIONS THAT NEED ANSWERS

- Why is lot size important?
- What does the scientific literature say about this subject?
- Based on the literature review, what should the minimum lot size be?

Summary:

Minimum lot size for properties developed with on-site sewage systems has changed little in Washington state since statewide on-site rules were first established in 1974. Although the Washington lot sizes were based on the area necessary for providing adequate treatment and disposal of the sewage generated, additional lot size determinants include what is needed to fit the development and on-site sewage components onto the lot while respecting the horizontal setback requirements, and what is needed to dilute nitrogen and other contaminants discharged with the treated wastewater.

Soil type and degree of slope are not lot size determinants beyond what is needed to fit the components onto the lot. Treatment strategies can be devised to provide the necessary public health and environmental protection.

If site risk and relative importance of the aquifer for human health is not a factor, then the scientific literature indicates that minimum lot size to prevent nitrogen degradation of the groundwater is roughly 0.5 to 1.0 acres when mitigation relies on dilution. Specific treatment to remove nitrogen could allow smaller lot sizes.

The scientific literature also has many references describing the nitrogen removal capacities for various on-site technologies. Values measured range from near zero to 90% removal. Many of these reports are summarized in this paper.

See the conclusions on page 5.

KEYWORDS:

Lot size, housing density, nitrate, nitrogen, pollution prevention, recharge, population density

Introduction:

In Washington state, minimum lot size is regulated in the on-site rules under WAC 246-272-20501 (Developments, Subdivisions, and Minimum land area requirements). This topic was contentious during the rule development that led to the 1995 rules and the same issues are still alive and perhaps made more salient by the ever-increasing development using on-site wastewater treatment and disposal technologies. However, before requiring additional treatment to remove nitrogen or to increase the lot size to reduce nitrogen impact, an analysis of the relative risk to human health or to downgradient surface water must be performed. Only high risk sites should be required to have larger lots or nitrogen removal treatment.

The main issues that affect minimum lot size are: (1) What is necessary to physically place the house, driveway, other development and the on-site sewage system and its reserve area on the property and still maintain the necessary setbacks? and (2) What is necessary to prevent degradation of groundwater with pollutants from the on-site system (pathogens, nitrates) and the other development on the property (impervious surfaces, landscaping fertilizers and other chemicals)?

The purpose of this review is to synthesize the literature available on the topic of minimum lot size so that the Technical Review Committee can make appropriate recommendations about this issue to the Rule Development Committee. Forty publications, which include peer-reviewed journal articles, conference proceedings and government reports were collected and reviewed. Even though the majority of the publications are conference proceedings, which are typically not peer reviewed, they provided useful information regarding this topic and many of the authors are highly respected researchers in the on-site field.

This literature review will describe what factors are used to determine minimum lot size, where we are now on this issue, and what is known from the scientific literature about the issues. In the conclusion section, a series of questions are posed for decisions by the TRC, based on the information provided.

Body:

FACTORS USED TO DETERMINE LOT SIZE

The purpose of minimum lot sizes is to assure that the development structures, driveways and the on-site sewage system (including the reserve area) will physically fit on the property while complying with all the required setbacks. At the same time, the goal of an on-site sewage system is to treat and dispose of wastewater in a manner which protects public health and the receiving environment. During our work on Technical Issue 4 (Disposal Component Reductions – Highly Pretreated Effluent), we found that properly designed, sited and installed and maintained on-site systems will remove bacterial and viral pathogens before the effluent reaches the groundwater. Remaining contaminants such as nitrates, chlorides and any organic solvents placed into the system usually depend on dilution to protect the groundwater. Lot size will affect the amount of dilution of the remaining contaminants in the effluent as it leaves the soil envelope before, or as it mingles with, the groundwater. Lot size also influences what other contaminants are added to the groundwater through gardening, fertilizer use, etc. Another factor that has been used in establishing lot size for properties developed with on-site sewage systems is a de facto approach to land use planning.

The lack of site-specific data and the inappropriate use of on-site sewage regulation for land use regulation have resulted in very arbitrary requirements for minimum lot size. In addition, on-site rules rarely are adjusted for performance capabilities of the wastewater treatment system used (EPA 2002).

WHERE WE ARE NOW

Currently in Washington state, WAC 246-272 establishes the minimum land area requirement for on-site sewage treatment disposal at 12,500 ft^2, although local health officers may issue a permit for smaller lots of record created prior to the 1995 rules if all other requirements of the WAC 246-272 can be met. When Method I is used, the total gross land area of a lot is included in the required minimum land area for a given soil type and source of drinking water. This area includes steeply sloped portions and area under surface water. When Method I is used for determining minimum lot size, the size varies depending on whether the water supply is public or on-lot, and also depending on soil type. When Method II is used, an analysis of 15-20 factors is required and in no case may the lot size be smaller than 12,500 ft^2 or 3.5 unit volumes of sewage per acre, and must exclude area under surface water. However, exceptions are allowed for lots with OSSs within the boundaries of a recognized sewer utility having a finalized assessment roll and for planned unit developments that meet a series of requirements. This set of minimum lot sizing criteria was based on what was needed to properly treat and dispose of the sewage and on the ability to fit the necessary items on the lots while meeting setback requirements.

During the last rule revision, the process bogged down for a while due to a large difference in perceptions of what was necessary for public health and for environmental protection from nitrogen and other entrained pollutants. In the end, the nitrogen issue was tabled and the rules moved forward without resolving the nitrate issue. Values for minimum land area were essentially unchanged from the previous version of the rules, dated 1983, which were a refinement of the values put forth in the first state-wide on-site rules dated 1974. Clearly the issue of nitrogen contamination of the groundwater has played a role in each of the rule development processes, and the increase in numbers of systems over the last 25 years raises the importance of addressing nitrogen loading to the groundwater from on-site wastewater systems.

Another, less important detail regarding lot size was added to the 1995 rules. These rules allowed a health officer to include the area to the centerline of a road or street right-of-way in the minimum land area calculation when certain criteria are met.

Currently, lots on Type 1A soils are not required to be overly large unless a conventional gravity sewage system is used. It is well recognized that the capacity of these soils to remove pathogens is poor to none. Therefore, the on-site rule specifically requires some form of treatment to remove pathogens before releasing the effluent to Type 1A soil. The Technical Issue paper devoted to Type 1A soils raises concerns about the adequacy of the current horizontal separation distances to retain viruses in these soils. Nitrogen is typically handled by dilution and therefore is handled no differently in Type 1A than in other soils.

The scientific literature on the subject of lot size falls roughly into two categories: (1) minimum lot size necessary to prevent groundwater degradation and (2) how to remove nitrates with on-site technology to allow smaller lots. A small third category relates to pathogen contamination of the groundwater, but this topic was adequately addressed with Technical Issue #4.

LOT SIZE TO PREVENT GROUNDWATER DEGRADATION

For soil absorption systems in sands, the only active natural mechanism for reducing nitrate concentration in wastewater is dilution with uncontaminated groundwater and rainfall additions on the property (Walker et al. 1973). A study reported by Holzer (1975) describes that the suitability of an area for the use of conventional septic tank systems was found to be a function of potential leaching field failure, groundwater contamination, and population density. A particular example discusses the hill area of eastern Connecticut.

Mathematical modeling studies have been proposed for determining minimum lot size, with guarded results. For example, a linear program model, which can relate distributions of regional ground-water quality to corresponding development scenarios, was applied to a sub area of Cape Cod, MA, starting with 1980 data and projecting future allowable growth patterns. Elemental water quality, elemental housing density, nondegradation water quality standards, the 1980 land-use pattern, and a projected development population are incorporated as constraints. The analysis elucidates optimal development distributions that produce a minimum ground-water-quality impact (Bauman and Schafer 1984). Perkins (1984) presents three mathematical models to predict lot size for limiting nitrate-nitrogen concentrations in groundwater. From these models, minimum lot size to provide minimum reasonable protection is 0.5 to l.0 acre based on reported data and 0.75 to l.0 acre based on models. Pizor, et al (1984) use a current planning capacity model for determining the number of habitants or dwellings that an area can support based on yield of potable groundwater and aquifer dilution capacity of nitrates. No numerical outcomes are given. The lot sizes determined from these studies do not take into consideration the risk to human health or degradation of downgradient surface water. Therefore such sizes would be recommended for the high risk sites and smaller sizes could be allowed for lower risk sites.

In review articles, Brown and Bicki (1987) and Bicki and Brown (1991) conclude that most studies on the correlation between groundwater contamination and OSS density estimate a minimum lot size necessary to ensure against contamination is roughly 0.5 to 1 acre. Kaplan (1988) quotes other authors about the utility of mathematical models for this issue: "The only conclusion to be drawn concerning the applicability of sophisticated ground water models to the problem of septic tank systems is that the utility of the models may be outweighed by their significant data requirements." He also credits another pair of authors, Bauman and Schafer, for having calculated that the nitrate standard would be exceeded if the lots were less than 1 to 2 acres and the groundwater moved less than 31 meters per year. Kimsey (1997) describes a methodology for estimating nitrate impacts to groundwater from on-site systems, but does not provide numerical data. Hantzche and Finnemore (1993) have developed a method for estimating long-term increases in groundwater nitrate caused by on-site sewage systems. The method has limited data requirements and uses straightforward computations. Comparisons of predicted values with actual field sampling data for several case study locations in California confirmed that the method provides reasonable first approximations of nitrate-nitrogen effects in groundwater from on-site systems. The major data input for this method is the amount of rainfall recharge and the model then predicts the resultant nitrate concentration for a given ratio of wastewater recharge to rainfall recharge. Using data from Olympia, which has an average rainfall of 45 inches per year, and assuming an average family of 3 (50 gal/capita) and a recharge rate of 75%, the total land area requirement would be 13,082 ft^2. If the recharge rate were 50%, then the area requirement would rise to 19,624 ft^2. At 40% recharge (Kimsey personal communication), the minimum land area would be 24,530 ft^2, or 0.56 acres.

Lichtenberg and Shapiro (1997) used data on NO_3 and hydrological characteristics of drinking water wells to relate land use practices to well water quality. They found that one on-site system is associated with about as much nitrogen leaching as one hectare (2.47 acres) of cornfield. Therefore, if conversion of a cornfield to residential use with on-site sewage is at a density of less than 1 on-site per hectare, the result will be lower N concentrations in the drinking water wells. Conversely, if the conversion is at a higher density of residences, there will be higher N concentrations in the drinking water wells. Tuthill and Meikle (1998) found a negative correlation between lot size and bacterial and nitrate contamination of wells, which means as lots get smaller, contamination increases. A recommended lot size is not given. Washington State Department of Ecology (2000) suggests a density of one on-site system per acre is sufficient to avoid ground water contamination. As stated previously, the lot sizes determined from these studies do not take into consideration the risk to human health or degradation of downgradient surface water. Therefore such sizes would be recommended for the high risk sites and smaller sizes could be allowed for lower risk sites.

Since minimum lot size is designed to protect public health and prevent environmental degradation, in terms of protecting these assets, it does not matter whether the lot is one of record or has been newly created.

HOW TO REMOVE NITRATES WITH ON-SITE TECHNOLOGY

Since nitrogen contribution to the groundwater is perhaps a major determinant of lot size where the risk to human health and / or downgradient surface waters is high, one way to avoid larger lot sizes is to remove the nitrogen before it reaches the groundwater. A number of studies have been published on nitrogen reduction processes for on-site sewage systems.

The usual process for reducing nitrogen is to nitrify the element in an aerobic process and then denitrify in an anaerobic process in the presence of a carbon source. Gold et al (1989) describe high levels of denitrification using anaerobic rock filters following aerobic sand filters, with the carbon source added to the anaerobic filters as either alcohol or gray water. Ball (1994) describes several methods of nitrogen removal. In one case, he reports up to 55% denitrification in a single-pass intermittent sand filter (ISF), depending on temperature. In addition, he reports further loss of nitrogen when the ISF effluent is placed in the biologically active topsoil stratum. He further reports results from some experimental systems where septic tank effluent is pumped continuously from the discharge end of the tank to a small trickling filter located over the inlet tee from which it drops back into the tank. The recirculation rate is low enough to maintain substantially anaerobic conditions in the septic tank. One septic tank so equipped discharges effluent that is markedly improved over untreated septic tank effluent. Biochemical oxygen demand is reduced by 92%, total suspended solids by 82%, and total nitrogen by 77%. When this relatively high-quality effluent is then dosed to an upflow filter, it is largely denitrified, so that less than 5 mg-N/L is discharged to the environment.

Boyle et al (1994) report on the results of an on-going field evaluation of several promising technologies for on-site nitrogen removal. A single field station with four parallel field-scale systems was built to provide side-by-side evaluations of recirculating sand filter-upflow anaerobic systems and peat filters. The anaerobic upflow-recirculating sand filter system has produced high quality effluent with low BOD and suspended solids. Total nitrogen concentrations below 15 mg/l as N were typically attainable. The peat filters produced high quality effluent with respect to BOD and solids but nitrogen removal to date has not been acceptable. Bruen and Piluk (1994) report on 3 variations of small recirculating sand filters that were monitored for effluent quality. One of these systems was able to remove 66% of the total nitrogen. Converse et al (1994) collected and analyzed soil samples from beneath and beside 13 mound systems. The nitrogen reduction as the effluent left the influence of the mound averaged 36%. Although this reduction was significant, the remaining nitrate is still 3.5 times higher than the MCL of 10 mg/L.

McKee and Brooks (1994) report nitrogen reductions through peat filters ranging from 21% to 82%. For systems serving residences, the numbers range from 36% to 83.6% removal with most of them averaging in the 5 to 13 mg/l range. The authors describe that the source of the peat is critical to high system performance. Mote and Ruiz (1994) report results from a laboratory study that employed 12 bench scale systems set up so that various combinations of the three variables could be studied. They found that a sand depth of 16.5 cm (6.5 inches) and a sand filter surface loading rate of 40.7 cm/day (9.9 gal/ft^2/day) of septic tank effluent was indicated as optimum for maximum nitrogen removal in a system combining a recirculating sand filter with an anaerobic upflow fixed-film reactor. Nitrification in the aerobic sand filter was enhanced by increased sand depth and reduced loading rate, whereas denitrification in the anaerobic fixed-film reactor was enhanced by reduced sand depth in the sand filter. Thus, recirculating sand filter systems can be operated in a manner that will promote appreciable removal of nitrogen from septic tank effluent without addition of external sources of energy to fuel denitrifying microbes. However, conditions for optimal nitrogen removal may not achieve satisfactory carbon removal (approximately 55%).

Osesk, Shaw and Graham (1994) report good nitrogen removal from two recirculating sand filter/denitrification systems. Samples were taken from the septic tank, sand filter, dosing chamber, and monitoring wells adjacent to the drainfields. One system discharged by gravity to a standard drainfield and one discharged to a mound. Nitrogen removal of at least 60% to 70% was achieved with these systems. Shaw and Turyk (1994) evaluated 14 pressure-dosed drainfields in sandy soils (1 at-grade, 6 standard PD, and 7 mound systems). The measured nitrate in the downgradient plume as well as the nitrogen to chloride ratios indicate that good bacterial removals were being achieved, but the systems did very little in the way of nitrogen removal. Loomis et al (2001) tested a variety of treatment systems for BOD_5, TSS, fecal coliform and total nitrogen. They found the nitrogen removal varied from 0 to 38%, depending on the system. The best removals were by recirculating systems. EPA (2002) summarizes current knowledge and lists some expected sustainable performance ranges for the most likely combinations of nitrogen removal processes. The percent removals are from 40 to 80%.

Mannion (1990) proposes the use of natural zeolites to mitigate nitrate pollution from on-site sewage systems. He asserts that zeolite absorbs the nitrate precursor, ammonium, at the source, and prevents nitrogen pollution effectively and inexpensively. He would merely substitute zeolite for the rock in drainfields and expects up to 90% removals. He reports that 10 yd^3 of zeolite would have enough exchange capacity to absorb ammonium from the effluent of a typical 2-bedroom house for 24 years at 100% efficiency and 30 years at 80% efficiency.

Cost Information:

The cost of larger lots or of not being able to develop an existing lot must be balanced with the cost of removing the contaminant that is forcing larger lot sizes. Nitrogen removal may add no cost to a system, or may add several thousand dollars, depending on what system for treatment is selected and how much nitrogen must be removed. Recirculating systems can remove significant amounts of nitrogen if the retention times and recirculating ratios are correctly selected. The recirculating systems may already be needed to meet some of the non-nitrogen parameters of the site. However, if an aerobic system or single-pass ISF is selected to meet the other parameters of the site, additional treatment processes must be added to reduce the nitrogen loading to the groundwater when needed, and in that case, considerable additional expense may be incurred.

Conclusions:

1. The minimum lot sizes for development with on-site sewage systems must meet two criteria: all the development (buildings, driveway, other pavement) and the sewage system must physically fit on the lot while maintaining the required setbacks and b) the lot must support the development without degrading the groundwater with nitrogen additions.
2. The minimum lot sizes in the 1995 version of WAC 246-272 are adequate for the physical placement of the structures and wastewater treatment system on the lot.
3. Larger lot sizes or nitrogen removal treatment should only be used for sites with high risk to human health or to downgradient surface water.
4. Mitigation of the nitrogen pollution of the groundwater with dilution will require lot sizes between 0.5 and 1 acre.
5. Several treatment technologies exist for removal of nitrogen from the on-site sewage train. Depending on the treatment chosen and therefore the amount of nitrogen removed before disposal, smaller lot sizes may be allowed as the nitrogen concerns are mitigated with removal processes before release to the groundwater. However, none of these treatment technologies has been tested under a recognized testing protocol.
6. Lot size should apply to existing lots as well as new lots if degradation of the receiving environment is an issue, since the degradation will occur regardless of when the lots are created.
7. Lot sizes for Type 1A soils should not differ from other soil types in terms of bacterial pathogens and nitrates, because there is little or no treatment rendered by this soil regardless of lot size. Adequate pretreatment for these contaminants must be designed into the system. However, the adequacy of these soils to retain and inactivate viruses is questionable and the current horizontal separation distances may not provide the needed protection. See the Issue Paper on Type 1A soils for more information.
8. Stacking of systems or houses on side slopes is not so much an issue of lot size as it is of soil depth. Therefore, this issue should be addressed elsewhere.

References:

Ball, HL. 1994. Nitrogen Reduction in an On-Site Trickling Filter/Upflow Filter Wastewater Treatment System, in Proceedings of 7th International Symposium on Individual and Small Community Sewage Systems, ASAE, St. Joseph, MI. Pp.499-503.

In a single pass through an Oregon-type intermittent sand filter (ISF), septic tank effluent is 90-99% nitrified and up to 50% denitrified, depending on the temperature. Significant additional denitrification occurs in soil disposal systems when ISF effluent is placed in the biologically active topsoil stratum. In environments particularly sensitive to nitrate levels, however, an even greater margin of safety may be required. While nitrate (NO_3) can be rapidly denitrified in the anaerobic conditions of a septic tank, most nitrogen in a septic tank is in the form of ammonia (NH_3), not NO_3. Trickling filters, on the other hand, are known to be efficient nitrifiers, readily converting NH_3 to NO_3. In experimental systems at several residential and small commercial sites, septic tank effluent is pumped continuously from the discharge end of the tank to a small trickling filter located over the inlet tee from which it drops back into the tank. The recirculation rate is low enough to maintain substantially anaerobic conditions in the septic tank. One septic tank so equipped discharges effluent that is markedly improved over untreated septic tank effluent. Biochemical oxygen demand is reduced by 92%, total suspended solids by 82%, and total nitrogen by 77%. When this relatively high-quality effluent is then dosed to an upflow filter, it is largely denitrified, so that less than 5 mg-N/L is discharged to the environment.

Bauman, BJ, Schafer, WM. 1984. Estimating Ground Water Quality Impacts from On-Site Sewage Treatment Systems, in On-Site Treatment – The 4th National Symposium on Individual and Small Community Sewage Systems, ASAE, St. Joseph, MI. Pp. 285-294.

A new nonpoint source pollution management model is presented and applied to ascertain scenarios of expanding residential/commercial land uses to minimize impacts on ground-water quality. The model is a linear program (LP), which can relate distributions of regional ground-water quality to corresponding development scenarios at optimality. This is achieved by including equations from a numerical steady-state transport model in the LP constraint set. The model is applied to 1980 data and projected conditions for a subarea of Cape Cod, MA. Elemental water quality, elemental housing density, nondegradation water quality standards, the 1980 land-use pattern, and a projected development population are incorporated as constraints. The analysis elucidates optimal development distributions that produce a minimum ground-water-quality impact. The dual variables generated from binding continuity, water quality, and development density constraints are particularly valuable for the information they provide on the impacts of relaxing land-use and water-quality limitations.

Bicki, T, Brown, R. 1991. On-site Sewage Disposal: The Influence of System Density on Water Quality, J. Environmental Health 53(5):39-42.

Effluent entering a soil absorption system may contain varying combinations and amounts of potential contaminants. A vertical separation distance of 24 inches between the bottom of a soil absorption system and the seasonally high water table has been suggested as a minimum soil depth for proper treatment of effluent and protection of groundwater. Depth to the wet season water table can be monitored with observation wells or can be estimated from soil morphological characteristics. Caution is advised when evaluating artificial drainage as a method to improve performance of on-site sewage disposal systems.

Population density determines the effluent load per unit land area and the concentration of contaminants in groundwater. Numerous studies employing groundwater monitoring and modeling have demonstrated a correlation between water contamination and on-site sewage disposal density. A survey of literature on density of systems indicates that in general a minimum lot size of one-half to one acre is needed to ensure against groundwater contamination. However, some studies have found groundwater contamination from nitrate with lot sizes in this range due to site specific soil, hydrogeologic and climatic conditions. Most studies relating density of on-site sewage disposal systems to groundwater contamination have focused on nitrate loading. Additional research focusing on other effluent constituents is needed to improve our understanding of system density and water quality.

Blount, JR, Anderson, RJ. 1996. Recognition, Evaluation and Correction of Failing On-site Sewerage Facilities, 4th Annual On-site Wastewater Treatment Research Council Conference. Pp. 140-147.

The authors discuss details from accumulated field experience related to recognizing, analyzing, correcting and preventing failures. They include tips and guidance for dealing with these elements of failure.

Boyle, WC, Otis, RJ, Apfel, RA, Whitmyer, RW, Converse, JC, Burkes, B, Bruch, MJ, Anders, M. 1994. Nitrogen Removal from domestic Wastewater in Unsewered Areas, in Proceedings of 7th International Symposium on Individual and Small Community Sewage Systems, ASAE, St. Joseph, MI. Pp. 485-498.

This paper presents the results of an on-going field evaluation of several promising technologies for on-site nitrogen removal. A single field station with four parallel field-scale systems was built to provide side-by-side evaluations of recirculating sand filter-upflow anaerobic systems and peat tilters. The wastewater from a correctional institution at this site receives septic tank processing followed by disposal through subsurface infiltration. A portion of the septic tank effluent has been diverted to the field station. The four parallel systems have been operated at conventional loading rates since November 1992. The septic tank effluent has exhibited qualities typical of household wastewater. The anaerobic upflow-recirculating sand filter system has produced high quality effluent with low BOD and suspended solids. Total nitrogen concentrations below 15 mg/l as N were typically attainable. The peat filters produced high quality effluent with respect to BOD and solids but nitrogen removal to date has not been acceptable.

Brown, RB, Bicki, TJ. 1987. On-Site Sewage Disposal – Influence of System Densities on Water Quality, Notes in Soil Science, Florida Water Resources Research Center, University of Florida. 7 pages.

This article addresses the impact of septic system density on ground water. It discusses the importance of scale when addressing the issue, describes a number of studies that deal with the topic and forms the conclusion that the minimum lot size necessary to ensure against groundwater contamination is roughly 0.5 to 1 acre, with some studies indicating even larger lot sizes necessary under some circumstances.

Bruen, MG, Piluk, RJ. 1994. Performance and Costs of On-Site Recirculating Sand Filters, in Proceedings of 7th International Symposium on Individual and Small Community Sewage Systems, ASAE, St. Joseph,

MI. Pp.329-338.

Three recirculating sand filter (RSF) sites were selected in Anne Arundel County, Maryland, for a detailed analysis and performance evaluation. Design modifications to the county's standard recirculating sand filter system were implemented at two of the sites to investigate reducing the size of the sand filter to 22.5 ft^2 and eliminating a separate pump pit tank. Reduced disposal trench sizes, as small as 12.5 feet by 3 feet, were investigated at all three sites to determine if improved RSF quality allows increased soil loading rates. Grab samples of septic tank, pump pit, and sand filter effluent were collected bi-weekly for pollutant concentration analysis. Documentation of pump hour meter readings allowed the determination of sand filter and trench loading rates. This paper presents results of this research project, including design details of the RSF system. The pollutant removal performance of the system is reported and conclusions are presented on the suitability of reduced trench sizes and increased soil loading rates for RSF effluent.

Converse, JC, Tyler, EJ, Litman, SG. 1994. Nitrogen and Fecal Coliform Removal in Wisconsin Mound System, in Proceedings of 7th International Symposium on Individual and Small Community Sewage Systems, ASAE, St. Joseph, MI. Pp.514-525.

Thirteen Wisconsin mound systems were evaluated for treatment effectiveness. Soil samples were collected from beneath the system at two locations at 15 cm (6 inch) increments to a depth of 105 cm (42 inches) beneath the aggregate. Adjacent soil samples were taken for background. The soil samples were analyzed for fecal coliforms, moisture content, TKN, ammonium, nitrate and chlorides. Fecal coliform concentrations at 103 MPN/g of dry soil, nitrate nitrogen concentrations of 34 mg N/L and chloride concentrations at 454 mg/L were found exiting the mound treatment area, which was identified as 90 cm (3 ft.) beneath the aggregate.

EPA. 2002. On-site Wastewater Treatment Systems Manual, EPA/625/R-00/008. Office of Water, Office of Research and Development, EPA. February 2002. 367 pages.

Gold, AJ, DeRagon, WR, Sullivan, WM, Lemunyon, JL. 1990. Nitrate-Nitrogen Losses to Groundwater from Rural and Suburban Land Uses, J. of Soil and Water Conservation, March-April 1990, pp. 305-310.

Nitrate-nitrogen (nitrate-N) losses to groundwater form septic systems, forests, home lawns, and urea- and manure fertilized silage corn were quantified and compared during a 2-year study. The septic system and all silage corn treatments had annual flow-weighted concentrations of nitrate-N in excess of 10 mg/l for at least 1 of the 2 years. In contrast, forest and both fertilized and unfertilized home lawn treatments generated flow-weighted nitrate-N concentrations of less than 1.7 mg/l. Annual losses ranged from greater than 70 kg/ha of nitrate-N from silage corn treatments to less than 1.5 kg/ha from unfertilized home lawns and forest. The results demonstrate the importance of unfertilized land use types in maintaining aquifer water quality; they also suggest that replacing production agriculture with unsewered residential development will not markedly reduce nitrate-N losses to groundwater.

Gold, AJ, Lamb, BE, Loomis, GW, KcKiel, CG. 1989. Nitrogen Removal Systems for On-Site Wastewater Treatment, in Proceedings of the 6th Northwest On-site Wastewater Treatment Short Course, University of Washington, Seattle, WA, Pp.288-303.

In recent years, the presence of nitrogen in human wastewaters has created serious health and environmental concerns. Leaching of nitrate-nitrogen (NO_3-N) from conventionally designed onsite sewage disposal systems has been shown to threaten both surface and groundwater quality in unsewered areas of the United States. In coastal regions, increased nitrogen inputs to estuaries and coastal ponds may promote surface water quality degradation, as nitrogen has been shown to be the limiting nutrient to eutrophication in these environments. Numerous investigators have found that NO_3-N concentrations can exceed the Federal drinking water standard of 10 mg/L in groundwater underlying areas which rely on onsite sewage disposal systems. This paper reviews the fate of nitrogen in conventional septic systems and presents the results of two types of "denitrification" on-site systems studied by the University of Rhode Island.

Hantzshe, NN, Finnemore, EJ. 1992. Predicting Ground-Water Nitrate-Nitrogen Impacts, Ground Water 30(4):490-499.

The buildup of nitrates in upper ground-water zones is a potential cumulative effect of on-site sewage disposal practices which is not addressed by standard siting and design criteria. Literature concerning the contribution and fate of nitrogen beneath septic tank disposal fields is reviewed. From these findings, convenient, simplified methods are developed for estimating long-term ground-water nitrate increases on an area-wide basis. The methods are presented in a manner useful to engineers, planners and regulatory agencies for routine evaluation of existing and proposed land developments and for design of large, common disposal systems. Typical solutions are shown graphically to illustrate the relative importance of various factors, including development density, rainfall recharge, and soil denitrification. Predicted values are compared with actual monitoring data for three California communities to verify the reasonableness of the suggested methods. Several possible regulatory applications are suggested.

Hatfield, K, Noss, RR, Samani, N. 1994. Minimum Impact Modeling of Nonpoint Source Ground Water Pollution, Journal of Irrigation and Drainage Engineering, 120(1): 149-167.

A new nonpoint source pollution management model is presented and applied to ascertain scenarios of expanding residential/commercial land uses to minimize impacts on ground-water quality. The model is a linear program (LP), which can relate distributions of regional ground-water quality to corresponding development scenarios at optimality. This is achieved by including equations from a numerical steady-state transport model in the LP constraint set. The model is applied to 1980 and projected conditions for a subarea of Cape Cod, MA. Elemental water quality, elemental housing density, nondegradation water quality standards, the 1980 land-use pattern, and a projected development population are incorporated as constraints. The analysis elucidates optimal development distributions that produce a minimum ground-water-quality impact. The dual variables generated from binding continuity, water quality, and development density constraints are particularly valuable for the information they provide on the impacts of relaxing land-use and water-quality limitations.

Hatton, B. 1992. Public Health Policy of Waterloo Region Towards Conventional and Alternative Septic Systems, Conference Proceedings on Alternative Septic Systems for Ontario, Waterloo Centre for Groundwater Research, Univ. of Waterloo. Pp. 59-74.

A boom in rural development of the Regional Municipality of Waterloo resulted in a potentially larger groundwater contamination problem from inadequate or overloaded septic systems. The Waterloo Regional Health Unit raised concerns in 1988 about the antiquated public policy regarding septic systems and after consultation with the Waterloo Centre for Groundwater Research, submitted a proposal for refining the current regulations to the Regional Council. In May, 1991, the Regional Council approved the recommended policy changes to include areas such as a new required minimum lot development size, complete hydrogeological information on the lots being developed and a public education program about septic systems.

Holzer, TL. 1975. Limits to Growth and Septic Tanks, Proceedings of the Rural Environmental Engineering Conference on Water Pollution Control in Low Density Areas, Paper No. 6, Pp.65-74.

The effect of septic tank effluent on groundwater quality may be a limiting factor for population growth. Data review of groundwater quality showed that, based on recharge, septic tank effluent could substantially contaminate groundwater if a large amount is discharged into regions where groundwater circulates in a very thin zone near the surface. The suitability of an area for the use of conventional septic tank systems was found to be a function of potential leaching field failure, groundwater contamination, and population density. The particular example discusses the hill area of eastern Connecticut. (SWF)

Kaplan, OB. 1987. Septic Systems Handbook, Lewis Publishers, Chelsea, MI, Pp.145-154.

This handbook gives principles and concepts necessary to understand septic systems. Subjects included are public health agencies and why they control domestic sewage, the "perk" test, soils and water movement, leachline size, various onsite disposal technologies, groundwater degradation by septic systems, nitrates in groundwater, sewage disposal and land use.

Katers, JF, Zanoni, AE. 1998. Nitrogen Removal, Water Environment and Technology, 10(3):32-36.

Nearly one-third of all homes in the United States have septic systems, a potential source of contamination for local and regional groundwater. Rural communities that rely on subsurface disposal systems and on private wells for drinking water face the greatest risk. Nitrogen, which typically is not removed in conventional septic tank systems, creates particular concern, because studies have linked nitrate directly with methemoglobinemia, a disease harmful to infants, and to increased incidences of stomach and esophageal cancer.

Kimsey, MB. 1997. Estimating Potential Impacts to Ground Water Quality from Nitrogen Loading, 9th NW On-site Wastewater Treatment Short Course and Equipment Exhibition Pp.143-157.

This article describes the Washington State Department of Ecology's program for predicting and quantifying groundwater contamination impacts from on-site wastewater treatment systems. Washington relies on a mass balance method that incorporates ambient groundwater nitrogen levels, nitrogen from precipitation, aquifer characteristics and groundwater dilution factors.

Lee, GF, Jones-Lee, A. 1993. Water Quality Aspects of Incidental And Enhanced Groundwater Recharge of Domestic and Industrial Wastewaters – An Overview, Proceedings of Effluent Use Management Symposium, AWRA 29th Annual Conference, Tucson AZ. Pp.111-120.

Groundwater is an increasingly important source of water supply for domestic and other purposes; its mining in some areas has created the need to enhance the recharge of aquifers. Enhanced groundwater recharge and recovery has focused concern on the chemical character of recharge waters and their impact on groundwater and aquifer quality/use. Another important source of groundwater recharge is river water that passes through the riverbed. Especially in the arid west, domestic and industrial wastewaters can comprise a large part of the dry-weather flow of rivers. This can result in significant incidental recharge of groundwaters by domestic and industrial wastewaters with their associated contaminants. Some regulatory agencies are becoming sufficiently concerned about the incidental recharge of groundwaters by wastewaters discharged to rivers that drinking water standards are being incorporated as NPDES discharge limits on wastewaters discharged to rivers and tributaries. Restrictions are also being placed on enhanced recharge waters. If groundwater quality is to be protected, there is need to consider the potential impacts of contaminants in point- and non-point-source discharge runoff on groundwater quality through incidental and enhanced recharge. This paper presents an overview of issues that should be considered in protecting groundwater systems from contaminants in wastewaters that recharge groundwaters.

Lichtenberg, E, Shapiro, LK. 1997. Agriculture and Nitrate Concentrations in Maryland Community Water System Wells, J. Environmental Quality 26(1):145-153.

The presence of NO_3-N in well water is a cause of growing concern throughout the USA. Previous studies indicate that agriculture is a major contributor to this problem. This study uses data on NO_3-N concentrations in drinking water wells, on hydrological characteristics of those wells, and on measures of agricultural activity and of the extent of residential land use to construct statistical relationships between land use and well water quality in Maryland community water system wells. Tobit regression was used to correct for truncation bias arising from the fact that NO_3-N was not reported at concentrations below 0.1 mg/L. Exponential and linear specifications were estimated; non-nested hypothesis tests indicated that the exponential specification fit the data better than the linear one. Deeper wells appear less vulnerable to NO_3-N contamination, wells in unconfined aquifers and especially limestone formations, more so. Broiler and corn (Zea mays L.) production were associated with higher NO_3-N concentrations in drinking water in both specifications, indicating that agriculture-oriented efforts aimed at preserving groundwater quality should be concentrated on corn and broiler production. Septic systems for waste disposal also appear to have a substantial impact on NO_3-N concentrations in drinking water, suggesting that land use planning measures such as minimum lot size zoning may be needed to prevent conversion of crop and livestock production to residential units relying on septic systems from exacerbating groundwater quality problems.

Loomis, GW, Dow, DB, Stolt, MH, Green, LT, Gold, AJ. 2001. Evaluation of Innovative On-site Wastewater Treatment systems in the Green Hill Pond Watershed, Rhode Island – A NODP II Project Update, in Proceedings of 9th National Symposium on Individual and Small Community Sewage Systems, ASAE, St. Joseph, MI. Pp. 505-514.

Treatment performance of seven full-scale innovative onsite wastewater treatment systems installed as remedial systems was evaluated for a one-year period. The systems installed consisted of three textile filters, one followed by a raised bottomless sand filter; one drip irrigation system with a flushable disk filter; one single pass sand filter; one modular peat biofilter followed by a UV light disinfection unit; and one fixed activated sludge treatment system followed by a UV light disinfection unit. Treatment performance of these systems was monitored monthly for BOD_5, TSS, fecal coliform, and TN. All sand, peat, and textile packed bed filters operating in a recirculating or single pass mode produced mean BOD_5 and TSS effluent that was typically between 1 and 8 mg/l. The fixed activated sludge treatment system effluent BOD_5 and TSS concentrations averaged 15 and 9 mg/l, respectively. TN reductions averaged 16 to 18% for the single pass sand filter and modular peat biofilter and approximately 34 to 38% for the textile filters. Mean TN concentrations in the fixed activated sludge treatment system and the one textile filter operating in a mixed effluent mode were 20 and 9 mg/l, respectively. The single pass sand filter achieved the highest level of fecal coliform reduction (3.6 logs), followed closely by the peat filter (3.4 logs) and then the textile filters (3 logs). Ultraviolet light disinfection units produced a high quality effluent with a mean between 0 and 278 fecal coliform counts/100ml. Blower motor modification experiments to lower operating cost of the fixed activated sludge treatment system resulted in a general reduction in treatment performance of all wastewater contaminants studied. Required operation and maintenance needs are outlined for the systems studied.

Mancl, K, Patterson, S. 2001. Twenty Years of Success in Septic Systems Management, in Proceedings of 9th National Symposium on Individual and Small Community Sewage Systems, ASAE, St. Joseph, MI. Pp. 332-339.

The Lake Panorama Onsite Wastewater Management District was formed in 1980. At the time it was formed about 300 homes were built at the lake development. Lake Panorama currently has 678 single family homes, 3 condo units, a church camp, beaches, 2 golf courses, 2 campgrounds, offices and maintenance buildings. Nearly all of the residential, non-residential and condo units use soil absorption systems. Once all systems were located, inspected and updated, inspections were found to be simple and quick. Beginning in 1986 inspections were conducted of all systems serving full-time residences every year and systems serving part-time residences every 2 years. During inspections the sanitarian checks the pump, looks for changes in landscaping, evidence of sewage surfacing and opens the inspection ports to check for sewage ponding. Septic tanks are opened for inspections every 3 years for full-time and 6 years for part-time residences. Each inspection takes about 10 to 15 minutes to complete. Estimated inspection costs were $30 per dwelling per year. System performance has been very good over the 18 years since inspections began. The malfunction rate, where seepage or a bleedout of sewage was detected during an annual inspection, was 1%.

Mannion, W. 1990. Zeolites: An Inexpensive, Effective Method for Reducing Nitrate Pollution from Septic Tanks (An Essay), 7 pages.

Zeolite, an abundant mineral found in the western U.S., is an alternative method available for mitigating nitrate pollution from on-site sewage disposal systems. It's simple, effective, and long lasting. This alternative method serves public policy goals by cleaning up a source of recharge for groundwater by facilitating implementation of local land use plans and by keeping barriers to home ownerships as low as possible.

McKee, JA, Brooks, JL. 1994. Peat Filters for On-Site Wastewater Treatment, in Proceedings of the 7th International Symposium on Individual and Small Community Sewage Systems, ASAE St. Joseph, MI. Pp.526-535.

The use of peat filters for on-site wastewater treatment is being considered in a number of jurisdictions as an alternative to the conventional septic system. The results of monitoring for ten (10) systems in the State of Maine and twelve (12) systems in the Province of Ontario are presented. These systems have been installed to serve a variety of uses including single and multiple family residential, schools, shopping plazas and restaurants. The preliminary results indicate peat filters provide significant treatment reductions for the nitrogen species (21-82 percent), biochemical oxygen demand (>90%), total phosphorous (>87%), and bacteriological indicators (99.9%). The preliminary conclusions are that peat provides an alternative to the conventional septic system for on-site wastewater treatment providing an effluent of higher quality, with a lower potential for adversely affecting groundwater quality.

McNeillie, JI, Anderson, DL, Belanger, TV. 1994. Investigation of the Surface Water Contamination Potential from On-Site Wastewater Treatment Systems in the Indian River Lagoon Basin, in Proceedings of the 7th International Symposium on Individual and Small Community Sewage Systems, ASAE St. Joseph, MI, Pp.154-163.

Rapid development in Florida and the decreasing water quality of Florida's estuaries have caused concern that new residential developments, which utilize onsite wastewater treatment systems (OWTS), may be contributing pollutants from septic tank effluent (STE) to Florida's surface waters. Currently, over 1.6 million households in Florida utilize OWTS (Ayres Associates, 1993a).

OWTS, typically consists of a septic tank and subsurface wastewater infiltration system (SWIS). They utilize the soil's ability to treat wastewater before entering the groundwater. The soil is capable of attenuating organic materials, inorganic substances, and pathogens in wastewater by acting as a filter, exchanger, adsorber, and a surface on which many other physical, chemical, and biological processes occur (Clements and Otis, 1980). When site and soil conditions are favorable, these systems generally produce water of acceptable quality for discharge into the groundwater. Under saturated soil conditions, however, the wastewater moves faster through the soil and may exceed the soil's capacity to properly treat the effluent, thus allowing water, which may be high in nutrients and other contaminants to enter groundwater. Thus, there is concern that high densities of OWTS in a given area and the resulting large volumes of wastewater may lead to groundwater and surface water contamination if housing density is increased or if suitable unsaturated soil thicknesses are not present.

Results of this study indicated that while unsaturated soils contribute significantly to the renovation of STE by various processes, the soil's ability to treat STE may not be indefinite and may be affected by groundwater conditions. Significant concentrations of STE pollutants were measured in groundwater directly below an OWTS, which commonly had saturated conditions within 30 to 60 cm (1 to 2 ft) below the SWIS. Despite this situation, concentrations of key pollutants in groundwater were indistinguishable from background levels within 12 m (40 ft) downgradient of the system.

Mesckhke J., Sobsey M-site Treatment Systems. 1998. Microbial Pathogens and On-site Treatment Systems, Proceedings of the 14th Annual On-Site Wastewater Treatment Conference: Securing the Future of On-Site Wastewater Systems. Pp. 90-97.

Onsite waste disposal systems (OSDS) are used to treat domestic waste for roughly 20% of the United States population (Scandura, 1997). These systems typically are comprised of an influent pipe from the house entering a septic tank, which serves as a settling chamber and anaerobic digester. The septic tank then connects to a distribution box which leads to the soil absorption field (SAF). Even under optimal conditions, very little treatment of microbial pathogens occurs in the septic tank. Biological stabilization and pathogen removal primarily take place in the SAF. Properly functioning absorption fields are effective in reducing microbes and pose little health risk. However, failure of an absorption field to eliminate pathogens can lead to contaminated groundwater. Approximately half of the drinking water used in the United States is derived from groundwater and nearly half of waterborne outbreaks are attributed to contaminated groundwater (Craun, 1985). Contamination of groundwater from OSDS failure has been implicated in up to 40% of groundwater attributed outbreaks (Cogger, 1988). This review summarizes the factors and conditions that affect pathogen occurrence and persistence in, and removal from septic tank effluent (STE).

Mote, CR, Ruiz, EE. 1994. Design and Operating Criteria for Nitrogen Removal in a Recirculating Sand Filter, in Proceedings of 7th International Symposium on Individual and Small Community Sewage Systems, ASAE, St. Joseph, MI. Pp.339-346.

A sand depth of 16.5 cm and a sand filter surface loading rate of 40.7 cm/day of septic tank effluent was indicated as optimum for maximum nitrogen removal in a system combining a recirculating sand filter with an anaerobic upflow fixed-film reactor. Nitrification in the aerobic sand filter was enhanced by increased sand depth and reduced loading rate, whereas denitrification in the anaerobic fixed-film reactor was enhanced by reduced sand depth in the sand filter. Interactions among sand depth, loading rate, and recirculation rate were investigated by simultaneously operating 12 bench-scale systems. A fractional factorial experimental design distributed multiple levels of the three variables among the 12 systems and permitted estimates to be made of optimum values for each variable.

Osesek, S, Shaw, B, Graham, J. 1994. Design and Optimization of Two Recirculating Sand Filter Systems for Nitrogen Removal, in Proceedings of 7th International Symposium on Individual and Small Community Sewage Systems, ASAE, St. Joseph, MI. Pp.319-327.

Removal of nitrogen from domestic wastewater prior to discharge to a soil absorption system can help protect groundwater from exceeding the nitrate standard. This is becoming of increasing importance in Wisconsin and elsewhere, as rural development increases and people demand high quality drinking water.

This study involved the design, installation, and evaluation of sand filter/denitrification systems on two private residences in Central Wisconsin. The recirculating sand filter design involves the use of 7571 liter (2000 gallon) septic tanks with wooden covers. To allow for easy access, the top of the cover is at the land surface. The systems have 5.1 cm (2 inches) of insulation around the tanks and in the cover to help maintain heat during Wisconsin's cold winter. The filter is made up of 41 cm (16 in) of 2.5 to 3.8 cm (1-1.5 inch) limestone overlain with 7.6 cm (3 in) of pea gravel an 61 cm (24 in) of coarse sand. Within the sand filter, a 61 cm (24 in) slotted PVC pipe serves as a pump chamber to recirculate waste to the sand filter, pump back to the septic tank for denitrification, and pump to the soil absorption system.

One of the sand filter systems was installed on a mound system, the other on a conventional gravity system. Samples from the septic tank, sand filter, dosing chamber, and monitoring wells adjacent to the drainfields are collected at least monthly, and analyzed for the nitrogen series, BOD, pH, and chlorides. Phosphorous and volatile organic chemicals are analyzed seasonally.

A series of studies have been conducted, varying the recirculation rate to the sand filter and septic tank to optimize waste treatment during different seasons. Nitrogen removal of at least 60 to 70% can be achieved with systems of this design, with fairly simple pump and flow regulation equipment. Design problems and success along with flow optimization results are discussed.

Perkins, RJ. 1984. Septic Tanks, Lot Size and Pollution Control, J. Environmental Health, 46(6):298-304.

Minimum lot size requirements purportedly provide protection against groundwater contamination. Three mathematical models are presented using nitrate-nitrogen concentrations. Minimum lot size to provide minimum reasonable protection is 0.5 to l.0 acre based on reported data and 0.75 to l.0 acre based on models. (SWF)

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 (0.5 to 1.0 acre) based on reported data, and from 0.3 to 0.4 ha (0.75 to 1.0 acre), based on theory.

Perkins, RJ. 1989. On-site Wastewater Disposal, Lewis Publishers, Chelsea, MI.

This book on on-site wastewater systems has a short chapter on Lot Evaluation, in which the author provides a general statement about lot size needs for protecting groundwater.

Pizor, PJ, Nieswand, GH, Hordon, RM. 1984. A Quantitative Approach to Determining Land Use Densities from Water Supply and Quality, J. Environmental Management, 18(1):49-56.

Discusses the history of lot size recommendations by land use planners. Lot size should be governed by volume and quality of water required from the underground aquifers. Defines Current Planning Capacity (CPC) as a lot sizing variable which measures the ability of a region to accommodate growth and development within limits defined by existing infrastructure and natural resource capabilities. Presents an example of determining CPC for areas serviced by infrastructure or by on-site systems and wells.

A current planning capacity model is presented for determining the number of habitants or dwellings that an area can support based on yield of potable groundwater and aquifer dilution capacity of nitrates. The model is intended as a tool for land use planners in determining minimum lot size recommendations. The outcome of the model will depend upon site specific assumptions such as aquifer productivity and wastewater flow rates. Application of the model to

Hillsborough Township, New Jersey is illustrated. (SWF)

Lot size recommendations are traditionally made by land use planners after examination of a variety of planning factors. Until recently, however, no specific linkage was made between the volume and quality of water and consequent lot size. As pressures mount on existing water supplies, these considerations become increasingly important. Current planning capacity (CPC) is a measure of the ability of a region to accommodate growth and development within limits defined by existing infrastructure and natural resource capabilities. A model for determining CPC is developed for areas serviced by infrastructure, or by on-site septic systems and wells. Infrastructure capacity is a function of water supply and sewerage treatment plant capacity, existing pipe sizes, and current demand. Current planning capacity calculations for on-site water supply potential are a function of the productivity of the underlying aquifer.

Prins, CJ, Lustig, KW. 1988. Innovative Septic System Management, J. Water Pollution Control Federation, 60(5):614-621.

Poorly installed and maintained septic systems pose a serious threat to groundwater quality, particularly in areas of high housing density. Even when properly installed and maintained, septic systems in vulnerable hydrogeologic settings may degrade groundwater. There are approximately 22 million septic systems that operate in the U.S. Together they introduce about one trillion gallons of effluent into the environment annually. Furthermore, those Americans most dependent on groundwater for drinking also use septic systems most frequently; 95% of rural Americans depend entirely on groundwater for domestic uses.

Robertson, WD, Blowes, DW. 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 ground-water monitoring at a newly installed, seasonal-use, domestic septic system located on poorly buffered ($CaCO_3$ equivalent content less than or equal to 1.6 wt.%) lacustrine silt, has revealed the development of an acidic ground-water plume. Acid, generated by the partial oxidation of effluent NH_4^+, 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, where NH_4^+ does, however, persist (> 2 mg/l, as N) and where DOC remains elevated (6-13 mg/l), is associated with high average concentrations of the trace metals Fe (4.7 mg/l), Al (1.9 mg/l), and Mn (3.6 mg/l). Attenuation of nitrogen along the plume core flowpath is indicated by a decrease in the N/Cl^- ratio from an effluent value of 1.7, to a plume value of only 0.5 after 4 m of subsurface flow. Increased SO_4^{-2} levels observed in the zone of N depletion suggest that attenuation can be at least partly attributed to reduction of plume NO_3^- by oxidation of reduced S present in the sediment. PO_4^{3-} has not migrated significantly beyond the infiltration bed gravel layer, demonstrating that PO_4^{3-} mobility is limited in these sediments (retardation factor >10).

Sandy, AT, Sack, WA, Dix, SP. 1987. Enhanced Nitrogen Removal Using A Modified Recirculating Sand Filter (RSF^2), in Proceedings of 5th National Symposium on Individual and Small Community Sewage Systems, ASAE, St. Joseph, MI. Pp.161-170.

This study evaluated the nitrogen removal capabilities of a novel granular media filter system termed recirculating sand filter with a rock storage filter or RSF^2. Power plant bottom ash replaced the sand media, the recirculation tank was replaced with a gravel storage filter lying directly beneath the bottom ash filter, and provisions were made to recycle the nitrified filter effluent back through the septic tank, to take advantage of the available carbon source. Nitrogen removals rates are reported from several permutations of the system setup. Up to 96% removals are reported.

Shaw, B, Turyk, NB 1994. Nitrate-N Loading to Groundwater from Pressurized Mound, In-Ground and At-Grade Septic Systems, in Proceedings of the 7th National Symposium on Individual and Small Community Sewage Systems, ASAE, St. Joseph, MI.

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 (NO2+NO3-N), ammonium (NH4-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 was 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.

Tuthill, A, Meikle, DB, Alavanja, MCR. 1998. Coliform Bacteria and Nitrate Contamination of Wells in Major Soils of Frederick, Maryland, J. Environmental Health 60(8):16-20.

An investigation was conducted on the hypothesis that inadequate septic system construction or placement may cause contamination of wells with coliform bacteria and/or nitrates. Specifically, two predictions were tested: 1. A negative correlation between lot size and coliform bacteria and nitrate contamination will exist in unsewered areas. 2. Coliform bacteria and nitrate contamination will decrease with increasing casing length. The relationship of coliform bacteria and nitrate levels to lot size and casing length was tested for all wells in unsewered areas (n = 832) and for wells in 10 soil groups in Frederick County, Maryland, to determine if septic system construction or placement contributed to well contamination. Coliform bacteria and nitrate contamination were negatively correlated with lot size. In addition, coliform bacteria levels were negatively correlated with casing length, and there was a trend toward nitrate levels being associated with casing length. The results suggest that septic systems may be a source of coliform bacteria and nitrate contamination of wells. The casing length required in well construction should be increased in areas where wells may be prone to coliform bacteria contamination if the minimum amount of casing is used.

Tyler, EJ. 2001. Hydraulic Wastewater Loading Rates to Soil, in Proceedings of 9th International Symposium on Individual and Small Community Sewage Systems, ASAE, St. Joseph, MI. Pp.80-86.

On-site wastewater infiltration rate into soil depends on the nature of soil clogging and soil characteristics. The rate of transmission of the infiltrated water through the soil away form the infiltration surface when a vertical flow restriction is present depends on the characteristics of the soil, the depth of the permeable soil horizons and the slope. A single table is presented to estimate design infiltration loading and hydraulic linear loading rates for on-site wastewater treatment systems using soil.

Walker, WG, Bouma, J, Kenney, DR, Olcott, PG. 1973. Nitrogen Transformations During Subsurface Disposal of Septic Tank Effluent in Sands: Ground Water Quality, J. Environmental Quality 2(4).

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. (AU)

Washington State Department of Ecology. 2000. Guidance Document for the Establishment of Critical Aquifer Recharge Area Ordinances, Washington State Department of Ecology, Water Quality Program, Prepared by Kirk Cook. 46 pages.

Yates, MV. 1985. Septic Tank Density and Ground Water Contamination, Ground Water, 23(5):586-591.

The consumption of contaminated groundwater accounts for over one-half of all waterborne disease outbreaks in the U.S., with septic tanks being most frequently reported as the cause of contamination. A history of disease outbreaks and the movement towards rural zoning ordinances is discussed. (SWF)

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