DETERMINING THE EFFECTIVENESS OF ON-SITE SEPTIC SYSTEMS FOR THE REMOVAL OF VIRUSES

PROJECT NUMBER 98-01/319

PREPARED BY:
BARNSTABLE COUNTY DEPARTMENT OF HEALTH AND THE ENVIRONMENT
SUPERIOR COURTHOUSE, ROUTE 6A
BARNSTABLE, MASSACHUSETTS 02630

PREPARED FOR:

MASSACHUSETTS DEPARTMENT OF ENVIRONMENTAL PROTECTION
BUREAU OF RESOURCE PROTECTION

AND

U.S. ENVIRONMENTAL PROTECTION AGENCY
REGION 1

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EXECUTIVE SUMMARY

In 1995, the Commonwealth of Massachusetts made significant changes to its regulations governing onsite septic systems to reflect advancements in the knowledge base of onsite wastewater treatment. While these changes reflect many of the advances in our understanding of the treatment for certain constituents, much was still not understood about the role of standard septic tank-leach fields in the treatment for pathogens, notably viruses. The need for this type of understanding was amplified when the state allowed the use of innovative/alternative (I/A) septic systems, which under certain approvals were allowed to compensate for certain deficiencies that an applicant might present (i.e. less distance to groundwater or less available soil absorption system area). While the efficacy of I/A for treatment of certain constituents was widely accepted, questions arose as to whether the "credits" granted to I/A technology were appropriate in light of the present knowledge base regarding pathogens. The purpose of this study was to determine the efficiency of standard septic systems for the removal of viruses and compare this performance with selected I/A technology. The study further endeavored to place the findings in context of recent literature and make recommendations for maximizing virus removal from onsite septic systems.

Results from our study were presented in many forums including two journals, four national meetings, two regional meetings, and two annual meetings of the Massachusetts Environmental Health Association. Copies of all presented/published papers are supplied herein. Although there is considerable research still to be conducted, this grant has allowed us to serve as a valuable resource to DEP and Boards of Health for issues regarding pathogens. Our research corroborates the decision by DEP to require pressure dosing of leachfields where I/A technologies receive "credits" for leachfield size or reductions to groundwater. A review of the literature along with concurring research under this grant compelled certain recommendations that are included in this report. The findings of this study will also be incorporated into revisions of training materials yet to be compiled and including the Department's "*Self-Pace Course in Title 5*" for local Boards of Health.

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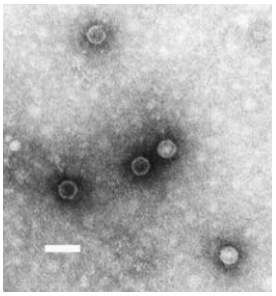

INTRODUCTION

What have we learned about viruses?

Since the beginning of our understanding of the role of improper human waste disposal in disease transmission, it is broadly accepted that wastewater systems should discharge their contents as far as practical from points of human exposure. Societies generally struggle, however with the question of *how far is enough?* Unfortunately, the lack of understanding sometimes results in debilitating human disease (evidence the polio[1] epidemics of the early 50's) and forces readjustments to our strategies. In response to the proposed National Primary Drinking Water Regulations: Ground Water Rule, published May 10, 2000, in the *Federal Register*, the American Society for Microbiology (ASM) commented that "Emerging contaminants, including new viruses, will be discovered in the future and effective monitoring programs must be in place". Their comments reflect our absence of a complete understanding of the various aspects of viral pathogens, their modes of transmission, and the various factors that determine their entrainment and persistence in groundwater. The overall goal of the present project is to incorporate the latest understanding of the various factors controlling the presence and persistence of septic-system-derived pathogens and incorporate this knowledge into recommendations for prudent practices that protect the public health.

Beginning in the early 1990's, the Commonwealth of Massachusetts began the process of evaluating The State Environmental Code 310 CMR 15.00 (commonly referred to as "Title 5"[2]), in order to incorporate the state of knowledge regarding sound environmental and public health principles into their requirements for the construction and siting of onsite septic systems. As a first step, the firm of DeFeo, Wait and Associates, Inc. was commissioned to perform a Technical Evaluation of Title 5. Although the review of the then-present state of

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[1] The illustration is that of a polio virus taken from the EPA website www.epa.gov/nerlcwww/images.htm

[2] Full citation: **THE STATE ENVIRONMENTAL CODE, TITLE 5: STANDARD REQUIREMENTS FOR THE SITING, CONSTRUCTION, INSPECTION, UPGRADE AND EXPANSION OF ON-SITE SEWAGE TREATMENT AND DISPOSAL SYSTEMS AND FOR THE TRANSPORT AND DISPOSAL OF SEPTAGE**.

science regarding viral pathogens in this evaluation was somewhat cursory, the final recommendations of the report included two important design recommendations that are now generally acknowledged as promoting better pathogen removal during onsite treatment and disposal. Although not explicitly incorporated for pathogen treatment, these recommendations included *the lowering of the hydraulic loading or application rate of effluent to the soil absorption system*, and the *increased vertical separation requirements between the bottom of the soil absorption system and estimated high groundwater in coarse soils*. Both these recommendations, subsequently incorporated into the regulations, are supported in theory by work of Marylynn Yates (1987) in a report for the Office of Groundwater Protection (USEPA) titled "Septic System Siting to Minimize the Contamination of Ground Water by Microorganisms" as well as other authors.

The minimal consideration of the virus issue in evaluations performed prior to 1990 is understandable in light of the fact that the majority of pertinent research has only more recently been conducted. For instance, 71 out of 135 articles (over 50%) referenced in a recent benchmark review of the removal of viruses in soil passage by Schijven and Hassanizadeh (2000) were published since 1990, and many of these were published only after 1995.

The purpose of the present study was:

- to conduct practical research in the area of treatment for viruses by standard onsite wastewater treatment systems
- to perform limited research on the treatment of viruses by standard and selected innovative/alternative onsite septic systems
- to present the results of the research in a wide variety of forums for training purposes and comments
- to make recommendations to the Commonwealth and local Boards of Health relative to ways that sound research can be incorporated into regulation and/or policies that protect the public health.

- To incorporate any recommendations made into training and educational outreach materials for Boards of Health.

RESULTS

In keeping with a primary objective, results of the research under this grant were presented in a variety of forums, beginning with a presentation of the study outline and concept before the National Onsite Wastewater Recycling Association at their annual meeting in 1997. The culmination of the research was recently presented at two wastewater treatment short courses (one in Washington State and one, the first of its kind, in New England). The various papers and their forums are presented below.

Heufelder, G. and S. Foss. 1997. Virus Transport Studies at an Alternate Onsite Septic System Testing Center in Cape Cod. Conference Proceedings, National Onsite Wastewater Recycling Association, College Station Texas, October 1997.

Heufelder, G. 1998. Survival of Viruses in Two Types of Onsite Systems. Conference Proceeding, National Onsite Wastewater Recycling Association, Ft. Mitchill Kentucky, October, 1998.

Heufelder, G. R. 1999. Preliminary Results: Virus Removal Efficiency of Newly-Started Trickling Filters and a Standard Leaching Trench. Environment Cape Cod. Vol. 1(3):86-90.

Higgins, J., G. Heufelder, S. Foss. 1999. Removal Efficiency of Standard Septic Tank and Leach Trench Septic Systems for MS2 Coliphage. In Seabloom, R.W. (Ed). Proceeding of the 10th Northwest On-Site Wastewater Treatment Short Course and Equipment Exhibition, September 20-21,1999, Seattle, Washington. Engineering Professional Programs, University of Washington, Seattle. Pp. 81-87.

Higgins, J., G. Heufelder, S. Foss. 1999. Removal Efficiency of Standard Septic Tank and Leach Trench Septic Systems for MS2 Coliphage. Small Flows Research. Vol 1(2).

Higgins, J., G. Heufelder, S. Foss. 1999. Removal Efficiency of Standard Septic Tank and Leach Trench Septic Systems for MS2 Coliphage. Environment Cape Cod. Vol 2(2). Pp 26-29.

Howes, B.L., J. Higgins, G. Heufelder and S. Foss. 2000. Removal of MS2 Coliphage Virus by Standard Septic Tank-Leach Trench Septic Systems. N.E. Water Environment Association Annual Meeting.

Foss, S., J. Higgins, and B. Berstene. 2002. Comparison of Standard Septic Tank-Leach Trench Septic Systems with Two Enhanced-Treatment Septic Systems for Attenuation of MS2 Coliphage. Proceeding of the 11th Northwest On-Site Wastewater Treatment Short Course and Equipment Exhibition, September April 3-4,2002, Seattle, Washington. Engineering Professional Programs, University of Washington, Seattle.

Foss, S., J. Higgins, and B. Berstene. 2002. Comparison of Standard Septic Tank-Leach Trench Septic Systems with Two Enhanced-Treatment Septic Systems for Attenuation of MS2 Coliphage. Proceedings of the First Onsite Wastewater Treatment Short Course and Equipment Exhibition. March 25-25, 2002. Newport, Rhode Island (in press)

In addition to these publications, the results of our efforts were also presented at two annual meetings of the Massachusetts Environmental Health Association.

The value and credibility of our work in regard to virus transport may also be measured by the number of times the work is cited in work of other researchers in the field. Our work was cited in at least two papers contained in the *Proceedings of the 9th Symposium on Individual and Small Community Sewage Treatment*. Fort Worth, Texas. American Society of Agricultural Engineers, St. Joseph, Michigan. These papers are authored by leading researchers in the field of virus transport beneath septic systems and our work is cited as a credible source of information. In addition, our research was again cited in a conference sponsored by the U.S. Environmental Protection Agency, Electric Power Research Institute, and the National Decentralized Water Resources Capacity Development Project, titled **National Research Needs Conference: Risk-Based Decision Making for Onsite Wastewater Treatment,** May 19 – 20, 2000 St. Louis, Missouri. Our work was cited in two "White Papers" (Design and Performance of Onsite Wastewater Soil Absorption Systems, co-authored by Robert L. Siegrist, Environmental Science and Engineering Division, Colorado School of Mines; E. Jerry Tyler, Soil Science Department, University of Wisconsin; and Peter D. Jenssen, Agricultural Engineering Department, Agricultural University of Norway, and Research Needs in Decentralized Wastewater Treatment and Management: Fate and Transport of Pathogens by Dean O. Cliver, Department of Population Health and Reproduction, School of Veterinary Medicine, University of California, Davis). Again, these authors cited our work as credible information on virus reductions in onsite septic systems.

Copies of all articles published under this grant are presented in the appendices.

RECOMMENDATIONS AND COMMENTS

As this project developed, we framed the information gathered and the literature reviewed around a series of practical questions relating to the changes in Title 5 that were promulgated in 1995, the allowances and credits given innovative/alternative technologies under Remedial Use Approvals, and local regulations that, for the most part, continued to exceed the requirements of Title 5 in many cases regarding horizontal setbacks to resources. These questions were:

- Do the changes made in Title 5 promote better removal of pathogens, particularly viral pathogens?
- What are the implications of the "credits" given to the use of innovative/alternative technology under their Remedial Use Approval letters? (this refers to the relief of 2 ft. of separation between the bottom of the soil absorption system and groundwater or the allowance for up to 50% reduction in the size of the soil absorption system when I/A technology is used)
- Is there continued justification for local increased setback requirements in certain situations?

Do the changes made in Title 5 promote better removal of pathogens, particularly viral pathogens?

Despite our research and considerable work by others, there are still many unanswered questions regarding the factors that influence virus transport both through the unsaturated (or vadose) zone beneath the septic system and in the saturated groundwater flow. There is, however nearly unanimous agreement that the primary treatment for viruses in the onsite septic system is in the vadose zone beneath the system. Additionally, the degree of "true" saturation greatly affects virus attenuation. Our early experiments with a new (hence immature) leaching trench showed virtually no removal of MS2 at a depth of 2 ft. beneath the bottom of the trench (Heufelder, 1999) as opposed to 99% removal in mature leach trenches

(Foss et. al. 2001). We posit that in the first situation, no biological mat had yet formed to promote a more even distribution of effluent over the entire infiltrative surface and there was in effect saturated flow to the collection lysimeters. In the second situation where a restrictive biomat promoted some “ponding” (suspension of a shallow depth of effluent across the entire bottom infiltrative surface), a more even distribution of effluent takes place. This situation (see Van Cuyk, S. and R.L. Siegrist, 2001) is generally conducive to better removal of pathogens.

The 1995 changes to Title 5 allowed for at least three changes that, in concurrence with the recent literature, promote virus attenuation. Foremost, the effluent loading rates (Specified in 310 CMR 15.242) were reduced. Ostensibly, these reductions reflected the concept of long-term acceptance rate (LTAR), but coincident work done by this author in 1991 (Heufelder, 1991) based on adjusted regression equations presented in Yates (1987) indicate that the new loading rates also theoretically promoted >5 log reduction in viruses in sandy soils (assuming a 5-ft vertical separation between the bottom of the leachfield and groundwater).

The second change in Title 5 that promotes better virus removal was the increased distance to groundwater required for “fast” soils (percolation rates <2 minutes/inch). This change is supported by literature summarized by Yates and Yates (1988) and others that indicate that certain viruses have been shown to vertically travel greater distances in coarser soils. Accordingly to force greater travel distances under unsaturated conditions would intuitively lead to greater virus removal and more hydraulic residence time and contact with reactive soil surfaces.

The third change in Title 5 that enhances virus removal unfortunately was not adopted in its fully recommended scope. The Technical Evaluation of Title 5 (DeFeo, Wait and Associates, Inc. 1991) concluded that wastewater distribution systems should promote more even distribution over the entire infiltrative surface. This could be achieved by reducing the distribution lateral diameter (even in gravity fed systems) and alternately dosing and resting the soil absorption system (Section 14.2 - DeFeo, Wait and Associates, Inc. 1991). These recommendations were only partially incorporated into Title 5. At this point, dosing of the soil absorption system is only required in system exceeding 2000 gal/day flow, and smaller diameter pipes on gravity systems are not allowed. Pressure dosing is also required under the Remedial Use Approval of all I/A technologies and will be discussed below.

The even distribution of effluent over the entire soil absorption system area addresses a critical feature that regulates virus removal in the vadose zone - the wastewater application rate. It is generally believed that until a mature biomat is formed, a standard gravity-fed soil absorption system is characterized by localized areas of higher application rates. That is, when a gravity-fed septic system is started, the effluent, exiting the lowest holes in the distribution laterals, exerts a locally high application rate in gal/sq ft/day compared with the theoretical design loading which assumes the discharge volume is spread over the entire *available* area. But until the genesis of a biomat causes uniform distribution of effluent over the entire available area, there are areas of application rates far exceeding the design loading (in gal/sq ft/day). This concept, most recently described in Van Cuyk, S. and R.L. Siegrist (2001), is generally understood and accepted. True lower wastewater application rates promote virus attenuation by encouraging lower effluent velocities across more soil surfaces. It is on the soil surface, particularly if the media is reactive toward the contaminant, that the virus is retained and often inactivated. Chu et.al.(2001) reports that, for instance, when metal oxides are present to "bind" with viruses (such as would be present in many sand sediments found in Barnstable County), flow velocities are inversely related to virus removal. Ryan et al. (in press) confirms that soils in Barnstable County have a reactive coating of iron oxides that offers the opportunity to maximize virus removal, if system designs encourage unsaturated flows.

We conclude that recent literature and understanding of virus transport in the vadose zone supports strongly the original recommendations by DeFeo, Wait and Associates. In areas with sensitive receptor sites (wells, downgradient recreational waters), all practical means to promote use of the maximum infiltrative surface within the shortest possible timeframe is warranted. Although this author is not aware of the results from gravity fed soil absorption systems using smaller diameter pipes, this seems to be one possible means of distribution that should be subject to further investigation. This later strategy may address the objections to pressure dosing: objections that are usually economically based. In seasonal situations, where the biomat is essentially restarted at the beginning of each season, this may be particularly relevant.

What are the implications of the "credits" given to the use of innovative/alternative technology under their Remedial Use Approval Letters?

The rationale for the requirement that all I/A systems receiving "credits"[3] must employ pressure dosing is unknown. It is, however, believed to be appropriate. At the initiation of the policy little was known about the pathogen reductions within the I/A technologies themselves. It was generally understood however, that the low organic loads of the I/A effluent would prolong the formation of a biomat, which as stated promotes uniform distribution in the soil absorption system. Since pathogen removal is enhanced by uniform distribution (and conversely pathogen removal is less when there is preferential flow), it was prudent to require some accepted mechanism to compensate for the lack of a biomat and that would promote uniform distribution. Pressure dosing promotes uniform distribution by more closely approximating the theoretical design application rate from the first day of operation. A *gravity-fed* system following secondary treatment causes preferential flow (and hence less pathogen removal) for an indefinite period. For instance, two standard leach trenches at the Massachusetts Alternative Septic System Test Center (MASSTC) exhibited a restrictive biomat in the leaching trench after two years of operation, while none of the advanced treatment systems have exhibited a restrictive biomat in this same time period.

Research conducted under this grant shows that while some systems (i.e. a "mature" trickling filter) remove between 0.5-1 log of viruses reliably, another type of I/A system (Fixed

[3] I/A systems in remedial situations are allowed to be sited two feet vertically closer to groundwater or are allowed to reduce the size of the receiving soil absorption system by 50% compared with no treatment.

Activated Sludge system) relied totally on retention time in the tank for reduction in viruses (see Foss et al, 2002).

Our observations at MASSTC indicate that I/A systems with gravity fed leaching trenches exhibit no restrictive biomat after two years of operation. Our further research demonstrates that I/A technologies themselves remove less that 99 % of the viral pathogens (Foss et al., 2002). These two findings beg the question as to whether the present requirement of pressure dosing following I/A technology[4] compensates adequately for the higher wastewater application rate (when the system is allowed with up to a 50% reduction in size) or reduction in hydraulic residence time (when given a 2 ft relief in the requirement for vertical separation to groundwater)? The inability to answer this question encourages prudence on the part of regulators when situating I/A technology near sensitive receptor sites. Our research does appear to confirm that the I/A technologies tested alone (with approximately 90-99% or 1-2 log removal) do not compensate for the 2 ft. of soil “credit” they receive, since this amount of soil achieves a 99-99.9% (2-3 log) removal of viruses under unsaturated conditions in a standard septic system after biomat formation. It is important to understand, however, that the biomat itself in our standard systems (as opposed to the merely the unsaturated conditions it promotes) may be responsible for some virus removal. Until we can segregate and understand the role of the biomat, we cannot conclusively determine the soil-depth equivalency of the I/A treatment-pressure dosed system. It would only appear from our early experiments with new leachfields challenged with virus loads, that without a biomat, *gravity fed* effluent from I/A technologies would receive limited, if any, further treatment for viruses in the soil passage. Further, this total treatment (I/A + gravity distribution) would not be as efficacious for virus removal as a standard system, despite its obvious advantage for other contaminants.

[4] Pressure dosing is a requirement in all I/A systems installed under Remedial Use Approvals.

A short word about Pressure Distribution Systems

This author believes that the design guidance for pressure distribution systems, particularly for treated effluent, should be investigated for improvements. At present, discharge holes may be spaced over five feet apart, and the majority of designs reviewed by this author are indeed placed at this interval. The reason for this common design feature likely is that the pump can be economically sized with the least number of holes. This author believes that design recommendations should include a "rotating" or "alternating" zone valve that sequentially changes the zones of a system that are fed. With this type of system, an intermediate-spaced set of distribution laterals could be placed and alternately dosed, more completely utilizing the soil infiltrative surfaces.

Is there continued justification for local increased setback requirements in certain situations?

There is perhaps no issue that has drawn more controversy when discussing onsite septic systems than the issue of vertical and horizontal setback requirements from points of potential exposure to humans. While Title 5 has provided a table (310 CMR 15.211: Minimum Setback Distances) with required setbacks, many communities have chosen to increase these setback requirements, ostensibly due to the belief that local conditions warrant such. The rationale behind many of these increased setbacks are, for the most part lost. So, the question remains – Are increased setbacks justified in light of published studies and our research?

To answer this question, we must first dissect the question into the two dimensional component parts: vertical and horizontal setbacks.

VERTICAL SEPARATION

Vertical separation refers to the separation between the bottom of the soil absorption system and the estimated seasonal high groundwater elevation. Title 5 specifies that this must be at least 4 feet in soils with a percolation rate of 2 minutes per inch or slower and 5 feet in soils where the percolation rate is less than 2 minutes/inch. Some towns have increased these vertical separation requirements. The purpose of the vertical separation is to provide for a treatment zone characterized by unsaturated flow of wastewater.

There is near unanimous agreement of researchers that the unsaturated or vadose zone beneath the soil absorption systems provides the most favorable opportunity for treatment for pathogens, particularly if the flow of percolate (from the leachfield) though this zone is unsaturated. To understand this concept, some explanation of terms is necessary. When a large volume liquid is poured over a porous media (such as sand), it immediately percolates downward in response to gravity, filling the voids between the particles, such that a large volume of the flow is conveyed through large pore spaces. This is referred to as *saturated flow* through the vadose zone. While some of the liquid is drawn away and dispersed laterally by capillary action and other physical forces, the greater the volume applied per unit area, the greater the percent of the applied volume flows downward through large pore spaces. Applying the same volume of liquid referenced above over a larger area results in the percolating liquid being less influenced by gravitational downward movement and more influenced by the physical forces that tend to disperse and direct the flow over the soil particles (as opposed to through the large pore spaces). Flow through the vadose zone that is characterized by a tortuous path of an entrained particle over the soil particle surfaces is referred to as *unsaturated flow*. One study (Powelson and Gerba, 1994) indicated that unsaturated flow conditions resulted in an average removal coefficient more than three times greater that saturated conditions.

Although a large number of numerical models (van der Heijde, 1996) have been developed to predict contaminant removal in the vadose zone, their application generally requires an unrealistic amount of site-specific knowledge to accurately predict contaminant removal. Despite the apparent complexity of the issue, however, certain principles have emerged that can be broadly applied.

More is Better (but let's keep it realistic) – Charles Gerba, a world-known microbiologist, in commenting on the white paper, *Research Needs in Decentralized Wastewater Treatment and Management: Fate and Transport of Pathogens*[5] states "Ideally, given enough depth all of the pathogens could be removed in the vadose zone". Further pointing out that in most regions of the country we are not afforded the opportunity to use this feature to have a significant impact on pathogen reduction, regulators are left with the question as to what the most reasonable/realistic vertical separation should be. The Commonwealth of Massachusetts is among a number of states that have vertical separation requirements of 4 ft. or greater. Although this feature is undoubtedly important, the oft-time inability to increase the required vertical separation, particularly in remedial situations, should compel Boards of Health to focus on more controllable features, such as those discussed below. Boards of Health can however, armed with an understanding of the principle that greater vertical separation translates to greater protection, incorporate this understanding into their decisions. For instance, when asked to grant variances near critical resources, and the applicant can reasonably locate the system to allow for greater vertical separation, they can encourage this strategy. If variances are requested from horizontal setbacks, but the applicant demonstrates significantly greater vertical separation than is required, the Board granting certain variances can feel comforted by the added protection afforded by the vertical component. Unfortunately, a direct determination of substitution (the amount of vertical separation that compensates for a given horizontal setback deficiency) is not possible at this time.

[5] National Research Needs Conference Proceedings: Risk-Based Decision Making for Onsite Wastewater Management – Final Report, March 2001.

<u>It's all in how you get it there – distribution systems</u> – Perhaps the most controllable aspect of the soil absorption system that can be modified to address the issue of pathogen removal is the distribution system. In the ideal situation, a well-matured layer of biological growth (biomat) at the soil interface will prevent preferential flow beneath the soil absorption system, in effect spreading the wastewater over the entire infiltrative surface. A particle (such as a virus) entrained in the percolate, will take a tortuous path downward passing across the surface area of many soil particles. If the soil particles are reactive toward the particle in any way, the particle may be adsorbed and its passage delayed if not indefinitely halted. In the case of a virus, the delay in its downward path may be long enough for it to become destabilized and be no longer infective.

Despite the ideal situation described above, the process of biomat formation can take months and even years to occur. In the case of treated effluent (where nutrients are removed), the biomat may never form to the point that it encourages unsaturated flow beneath it. In the formative stages of a standard septic system, the flow beneath the soil absorption system is saturated flow. Saturated flow is characterized by passage through the large pores in the receiving soil. In this instance, an entrained particle avoids the many potentially reactive soil surfaces and makes a comparatively more rapid downward passage through large pore spaces until it encounters groundwater.

In real situations, the above processes occur to varying degrees in nearly every septic system and hence it is rarely an "all or none" situation. The underlying principle, however, is that the more the effluent is evenly distributed over the entire surface infiltrative area, the more the flow is unsaturated and the higher the expected pathogen removal. Boards of Health, with understanding of this principle, can incorporate pressure distribution into their decisions when they desire to maximize protection from pathogens. For instance, if under Local Upgrade Approval, an applicant wishes to reduce the vertical separation between the bottom of the soil absorption and the groundwater, the Board might consider pressure distribution as a mitigating strategy in areas where the potential for human exposure is high (wells, bathing beaches, shellfish areas). Conversely, Boards of Health might not require this added expense in areas where the risk of exposure is very low. The negative aspect of pressure distribution systems is the fact that they require quarterly maintenance at the homeowner's expense.

HORIZONTAL SETBACKS

Even more controversial than the than vertical separation requirements is the issue of appropriate horizontal setbacks to critical resources. It is often argued that the Commonwealth's setbacks are already too restrictive, and that further more restrictive requirements are unwarranted. The argument advances that if the state-required setbacks were inadequate, one would observe many more illnesses that we presently do.

While the later argument might be countered with statistics to show that our actual surveillance for waterborne diseases is not adequate to detect many problems, this particular issue is outside the realm of this report. Many field investigations show that viruses, once in groundwater, can travel considerable distance. In a study pertinent to our area (carried out in a shallow sandy soil aquifer) Vaughn et al. (1983) detected enteroviruses > 100 ft. from the source (a leaching system for a housing complex). Other investigators (DeBorde et al. 1999, Literature Summarized in Heufelder and Rask, 1999) have found similar results, however, many studies report only limited entrainment of virus beneath septic systems. This author believes that preponderance of the investigations suggest that viruses are highly mobile in groundwater. Accordingly, at least in sandy soil aquifers, I believe that the 100 ft. horizontal setback requirement between soil absorption system and a critical resource (the most common local amendment to Title 5) is justified and can be supported with credible science. The contended sensitivity of shallow sandy soil aquifers to virus contamination is supported by statements of the American Microscopical Society, which in its comments regarding the proposed Groundwater Rule supported the EPA Drinking Water Committee Science

Advisory Board's (DWCSAB) recommendation that sandy aquifers also be designated as sensitive (along with karst, gravel and fractured rock aquifer settings).

CONCLUSIONS

The issue of viruses from onsite septic systems has many aspects that preclude a simple generalized approach. Despite considerable research by ourselves and others actually on Cape Cod (Bales et al. 1995, Pieper et al. 1997, Ryan et al, in press, and others), many of the variables necessary to accurately predict virus entrainment beneath septic systems are still unknown. Numerical models generally require an unrealistic number of input variables and would prove too cumbersome to assist in the determination of any meaningful best management practice. Nevertheless certain principles are revealed in the literature that can assist in engaging in prudent design practices to minimize virus contamination. Research in this report suggests that innovative/alternative septic systems of themselves may not treat for viruses to an appropriate degree. Due to the low infective doses assumed for viruses, even a 99.9% (3 log) removal might prove inadequate if the remaining soil treatment following disposal is nonexistent, as was suggested by our earliest work (Heufelder, 1999). The literature strongly suggests that the majority of treatment for viruses occurs in the vadose or unsaturated zone beneath the soil absorption system. It further suggests that the degree of saturation is inversely related to virus removal (the greater the saturation the less the virus removal). Given these two widely accepted premises, the achievement of low actual effluent loading rates would appear the best strategy to minimize virus contamination in groundwater. This can be achieved by pressure dosing the leachfield. The literature support the continuance of the policy to require pressure dosing in situations where I/A technologies are granted certain credits for reduction in leachfield size or distance to groundwater between the soil absorption system and the groundwater. This author believes that any further credits granted I/A technologies should only be done if disinfection is required prior to discharge. This would include situations where I/A technologies are granted additional relief from horizontal-setback requirements by Boards of Health. Again, the literature strongly supports the concept of achieving uniform distribution of effluent over the entire infiltrative surface of the soil absorption system to minimize virus breakthrough. In the early stages of standard septic system biomat genesis, as well as when discharging treated effluent under gravity distribution, the locally high effluent loading rates contradict the goal of virus removal.

As with any research project, we identify a number of research needs. These include:

- The need to quantify the benefit of pressure-dosed leachfields for the removal of viruses;
- The need to determine the role of the biomat in virus removal;
- The need to identify practical ways to disinfect treated effluent prior to discharge to leachfields;
- The need to reassess the most recent numerical models to identify if there are opportunities to incorporate their use into design criteria, and:
- The need to research findings of virus studies done in conjunction with EPA Ground Water Rule to determine whether these finding have relevance to onsite septic system placement near various potential exposure locations (wells, beaches, shellfish areas).

The issue of viruses in onsite wastewater systems will always be fraught with uncertainties. The incorporation of the best science in order to minimize potential exposure to this pervasive type of pathogen or to develop risk assessment models portends to be a significant challenge to public health officials into the foreseeable future. The sensitivity of certain aquifers (our in Barnstable County included), however, compels us to attempt to develop the most conservative approach in our wastewater disposal practices.

REFERENCES CITED

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

Chu, Y., Y. Jin, M. Flury, and M.V. Yates. 2001. Mechanisms of Virus removal during transport in unsaturated porous media, *Water Resour. Res.*, 37, 253-263.

DeBorde, Dan, C. W. Woessner, Q. T. Kiley, and P. Ball. 1999. Rapid Transport of Viruses in a Floodplain Aquifer. *Wat. Res*. Vol 33(10):2229-2238.

DeFeo, Wait and Associates, Inc. 1991. Technical Evaluation of Title 5 The State Environmental Code 310 CMR 15.00. A report to the Massachusetts Department of Environmental Protection. 376 pp. + References

Heufelder, G.R. and S. Rask. 1997. A Self-Pace Course in Title 5 Designed Especially for Board of Health Members. Barnstable County Department of Health and the Environment, Barnstable, Massachusetts.

Heufelder, G.R. 1991. Material Concerning Proposed Board of Health Regulations. A Project Report submitted to the EPA Buzzards Bay Project in fulfillment of a grant.

Pieper, Ann P., J. Ryan, R. W. Harvey, G. L. Amy, T. H. Illangasekare, and D. Metge. 1997. Transport and Recovery of Bacteriophage PRD1 in a Sand and Gravel Aquifer: Effect of Sewage-Derived Organic Matter. *Environ. Sci. & Technol*. 31(4):1163-1170.

Powelson, David K. and C. P. Gerba. 1994. Virus Removal from Sewage Effluents During Saturated and Unsaturated Flow Through Soil Columns. *Wat. Res*. Vol 28(10):2175-2181.

Ryan, Joseph N, R.W. Harvey, D. Metge, M. Elimelech, T. Navigato, and A. Peiper. 2002. Field and Laboratory Investigations of Inactivation of Viruses (PRD1 and MS2) Attached to Iron Oxide-Coated Quartz Sand. *Environ. Sci. & Technol*. (In Press)

Siegrist, R.L. and S. Van Cuyk. 2001. Wastewater Soil Absorption Systems: The Performance Effects of Process and Environmental Conditions. *Proc. 9th Natnl. Symp. On Individual and Small Community Sewage Treatmen*t. ASAE, St. Joseph, MI.

Schijven, Jack, F. and S. M. Hassanizadeh. 2000. Removal of Viruses by Soil Passage: Overview of Modeling, Processes, and Parameters. *Crit. Rev. in Environ. Sci. and Tech*. 30(1): 49-127.

Van Cuyk, S. and R.L. Siegrist (2001). Pathogen Fate in Wastewater Soil Absorption Systems as affected by Effluent Quality and Soil Clogging Genesis. In: Onsite Wastewater Treatment. ASAE no. 701P0101, Amer. Soc. Agricultural Eng., St. Joseph, MI. pp.125-136.

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

van der Heijde. 1996. Project Summary Compilation of Saturated and Unsaturated Zone Modelling Software (Update EPA/600/R-93/118 and EPA/600/R-94/028. U.S.E.P.A. National Risk Management Research Laboratory, Ada, OK 74820. EPA/600/SR-96/009. March, 1996.

Vaughn, J. M., E. F. Landry, C.A. Beckwith, and M.Z. Thomas. 1981. Virus Removal During Groundwater Recharge: Effects of Infiltration Rate on Absorption of Poliovirus to Soil. *Appl. Environ. Microbiol*., 41, 139-147.

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. *Appl. Environ. Microbiol*. 45:1474-1480.

Yates, Marylynn V. 1987. Septic Tank Siting to Minimize the Contamination of Ground Water by Microorganisms. U.S.E.P.A. Office of Ground-Water Protection, Washington, D.C. 87 pp.

Yates, M.V, and S.R. Yates. 1988. Modeling Microbial Fate in the Subsurface Environment. *Crit. Rev. in Environ. Control*. Vol. 17(4):307-344.

APPENDIX

DETERMINING THE EFFECTIVENESS OF ON-SITE SEPTIC SYSTEMS FOR THE REMOVAL OF VIRUSES

PROJECT NUMBER 98-01/319

Contents

Foss, S., J. Higgins, and B. Berstene. 2002. Comparison of Standard Septic Tank-Leach Trench Septic Systems with Two Enhanced-Treatment Septic Systems for Attenuation of MS2 Coliphage. Proceeding of the 11th Northwest On-Site Wastewater Treatment Short Course and Equipment Exhibition, September April 3-4,2002, Seattle, Washington. Engineering Professional Programs, University of Washington, Seattle.

THIS SAME PAPER (IN PRESS) WAS PRESENTED IN Proceedings of the First Onsite Wastewater Treatment Short Course and Equipment Exhibition. March 25-25, 2002. Newport, Rhode Island (in press)

Howes, B.L., J. Higgins, G. Heufelder and S. Foss. 2000. Removal of MS2 Coliphage Virus by Standard Septic Tank-Leach Trench Septic Systems. Presentation N.E. Water Environment Association Annual Meeting.

Higgins, J., G. Heufelder, S. Foss. 1999. Removal Efficiency of Standard Septic Tank and Leach Trench Septic Systems for MS2 Coliphage. Small Flows Research. Vol 1(2).

THIS SAME PAPER (copy not included) was presented in Proceeding of the 10th Northwest On-Site Wastewater Treatment Short Course and Equipment Exhibition, September 20-21,1999, Seattle, Washington. Engineering Professional Programs, University of Washington, Seattle. Pp. 81-87.
and
Higgins, J., G. Heufelder, S. Foss. 1999. Removal Efficiency of Standard Septic Tank and Leach Trench Septic Systems for MS2 Coliphage. Environment Cape Cod. Vol 2(2). Pp 26-29. (copy not included)

Heufelder, G. R. 1999. Preliminary Results: Virus Removal Efficiency of Newly-Started Trickling Filters and a Standard Leaching Trench. Environment Cape Cod. Vol. 1(3):86-90.

Higgins, J., G. Heufelder, S. Foss. 1999. Removal Efficiency of Standard Septic Tank and Leach Trench Septic Systems for MS2 Coliphage. Environment Cape Cod. Vol 2(2). Pp 26-29.

Heufelder, G. and S. Foss. 1997. Virus Transport Studies at an Alternate Onsite Septic System Testing Center in Cape Cod. Conference Proceedings, National Onsite Wastewater Recycling Association, College Station Texas, October 1997.

REMOVAL OF MS2 COLIPHAGE BY STANDARD SEPTIC TANK –LEACH TRENCH SEPTIC SYSTEMS

John Higgins[1], George Heufelder[2],
Sean Foss[2], and Brian Howes[3]

INTRODUCTION

The Alternative Septic System Test Center (ASSTC) located at the Otis Air National Guard Base in Sandwich, Massachusetts is a collaborative undertaking involving the Buzzards Bay Project, the Barnstable County Department of Health and the Environment, the University of Massachusetts Center for Marine Science and Technology, and the Massachusetts Department of Environmental Protection (MADEP). Designed to assess the efficiency of alternative and innovative (I/A) onsite wastewater treatment technologies, this newly constructed facility has received support from the USEPA Environmental Technologies Initiative (ETI) Program, MADEP, Massachusetts Environmental Trust, Barnstable County and others.

The ongoing verification testing at the ASSTC is one part of the Commonwealth of Massachusetts' overall effort to facilitate and promote new and innovative environmental technologies. The role of the ASSTC is to provide I/A technology vendors with both the opportunity to accelerate Massachusetts regulatory approvals and to reduce the substantial cost of the monitoring necessary to receive permits for sale of onsite systems in Massachusetts. The information collected at the ASSTC may also be useful in obtaining approvals for I/A elsewhere.

At the ASSTC, treatment efficiencies of both I/A and standard septic systems are evaluated over two year test-cycles based upon numerous standard wastewater and nutrient related parameters. All systems are operated in triplicate and receive residential wastewater from the Otis Air

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[1] Massachusetts Department of Environmental Protection Training Center, 50 Route 20, Millbury, Massachusetts 01527
[2] Barnstable County Department of Health and the Environment, Superior Courthouse, Route 6A, Barnstable, Massachusetts 02630
[3] Center for Marine Science and Technology, University of Massachusetts, 706 Rodney French Blvd, New Bedford, MA 02744

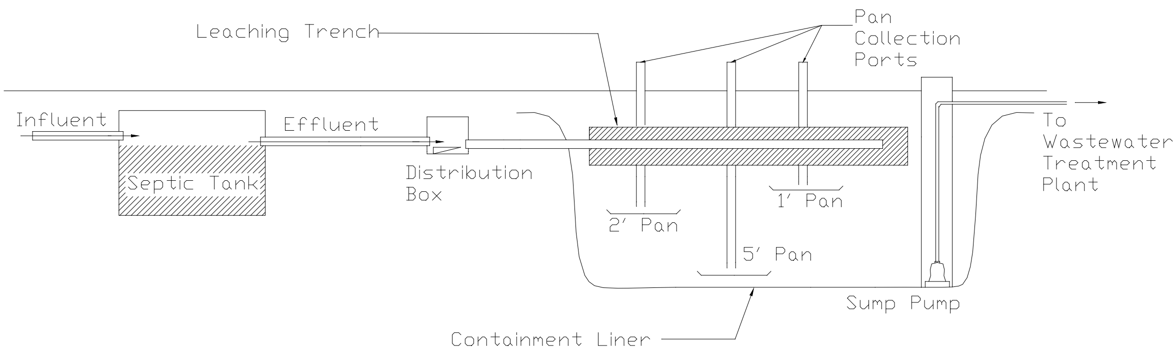
National Guard Base sewage system. An additional mission of the ASSTC is to develop and test new protocols and parameters to be used for evaluation of onsite systems. Part of this effort involves the transport of viruses both within I/A and standard septic systems and leaching fields. While this effort is still in its initial stages, this paper presents the initial data on virus transport throughout the treatment process within standard septic tank-leachfield systems and preliminary results of removals by various I/A technologies.

METHODS AND MATERIALS

Three standard septic tank – leaching field systems (Massachusetts Title 5) were tested for virus removal. These systems, which are the primary focus of this paper, serve as controls for comparison to the alternative technologies at the test facility and benchmarks for onsite systems currently in the field. Each of the triplicate systems includes a 5678 l (1500 gal) single-compartment septic tank, a Dipper™ distribution box, and a leaching trench with bottom and sidewall dimensions of 0.61 m (2 ft). The trenches were installed in medium sand fill that met the Massachusetts specifications for fill material (<5% pass a #200 Standard Sieve). The hydraulic loading rate was adjusted to 3 cm d^{-1} (0.74 gal ft^2 d^{-1}) with weekly calibration. The leaching fields are situated within lined basins to allow pumping of all leachate to an adjacent Wastewater Treatment Facility and prevents any interactions with the groundwater system. Water samples were collected from the influent, septic tank effluent, pan collection devices located at elevations of 30.5 cm (1 ft), 61 cm (2 ft), and 152 cm (5 ft) beneath the base of the leaching trench, and in the sump underdraining the leaching facilities at elevation 168 cm (5.5 ft) below the leaching trenches (Figure 1). Additional, influent/effluent sampling was conducted on four I/A technologies: open-cell foam trickling filter, layered sand filter, activated sludge, recirculating sand filter. These data were used to assess their relative viral removal rates from influent wastewater before discharge to the leaching field compared to the standard septic tank system.

Figure 1

Schemata of standard onsite septic system located at the Alternative Septic System Test Center. Leaching field is enclosed in a watertight liner draining to a sump. Sampling for MS2 coliphage was from influent, effluent, in pan collectors and sump outflow.



To avoid the problems associated with the handling of human pathogenic viruses, a surrogate virus, MS2 male-specific coliphage, was chosen because it is innocuous and approximately the same size and shape as pathogenic animal viruses commonly found in wastewater. In brief, the method of detecting these viruses in wastewater entails: collecting a water sample, removing the bacteria from the sample by filtration or by adding antibiotics to the media, depositing serial dilutions of sample into agar filled petri dishes along with a host bacteria that selectively promotes the growth of the desired virus, and incubating the petri dishes for approximately 16 hours at 35.7^{o}C. The appearance of plaques (absence of bacterial growth within an otherwise dense growth pattern) signifies the presence of viable viruses. Plaque numbers ranging from 20–100 plaques per plate are considered appropriate for statistical purposes. The preparation of plates from 3-4 different levels of diluted sample is generally required to ensure that the appropriate density of plaques is obtained. All plates are run in triplicate and control plates are run to test the sterility of all media.

Experiments conducted during May–August 1999, in collaboration with Dr. Oscar Pancorbo, Massachusetts Department of Environmental Protection, Wall Experimental Station, Lawrence Massachusetts, determined that ambient levels of MS2 coliphage within the incoming wastewater to the ASSTC were adequate for evaluating removals by onsite treatment systems. Our prior studies of field septic systems required the seeding each septic tank with a known concentration of MS2 coliphage and collecting samples over a period of weeks to months until the virus reached pre-seeded levels (generally < 10 pfu/ml). These pulse studies raised concerns over the applicability of following a single high titre (10^{5-6}) of virus, when the more common condition is a more constant influx. The finding of elevated levels of MS2 virus (10^4) in incoming sewage (from approximately 600 housing units at the U.S. Coast Guard unit on the Massachusetts Military Reservation) yields the opportunity for testing under "continuous injection" or "steady state" conditions.

Three types of experiments were conducted from June-August 1999. First, time-series sampling of the concentration of MS2 coliphage in the influent wastewater was carried out to ensure that calculations based on steady state were valid and to yield the influent concentrations for removal studies. Second, temporal sampling of MS2 coliphage levels at each of the five locations within each of the triplicate standard septic systems was conducted to evaluate removals of MS3 coliphage within the different system components. Third, effluent sampling of four I/A technologies (open-cell foam trickling filter, layered sand filter, activated sludge, recirculating sand filter) was used to determine MS2 coliphage removals for comparison to those within the standard septic systems.

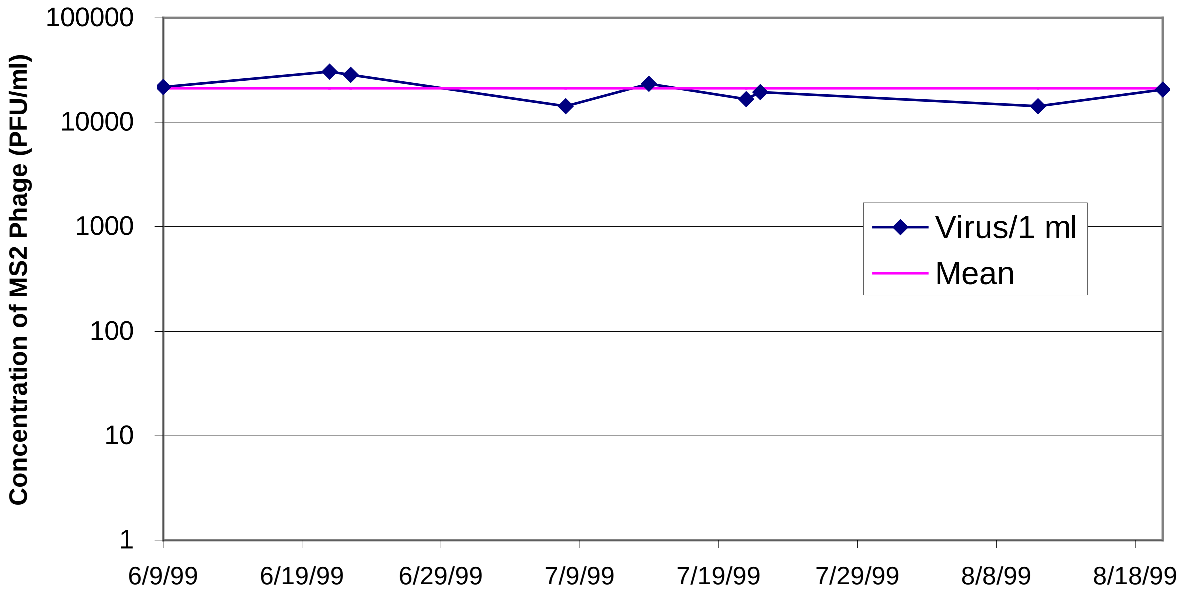
RESULTS AND DISCUSSION

Both standard septic systems and alternative innovative onsite technologies were found to significantly reduce the virus levels in influent residential wastewater, as measured using the MS2 coliphage assay. Variations in removal rates were found between the different I/A technologies. Additional reductions in virus levels were observed with passage of effluent through the standard leach field.

Time-course measurements of ambient MS2 coliphage levels within the influent wastewater to the ASSTC allowed for evaluation of virus removals using a continuos relatively constant source of MS2 coliphage to each technology for a period of about 2 months. The influent levels were stable and relatively high (21000 PFU/mL) throughout the experimental period (Figure 2). However, MS2 coliphage levels can vary seasonally at the test facility (unpublished data), so that temporal sampling of influent and effluent is conducted throughout all virus removal determinations. The constant delivery of MS2 coliphage to the test systems, allowed for the pooling of results from parallel sampling from locations within the systems. Therefore, evaluation of virus removal includes variability in system performance during normal operation over a summer season.

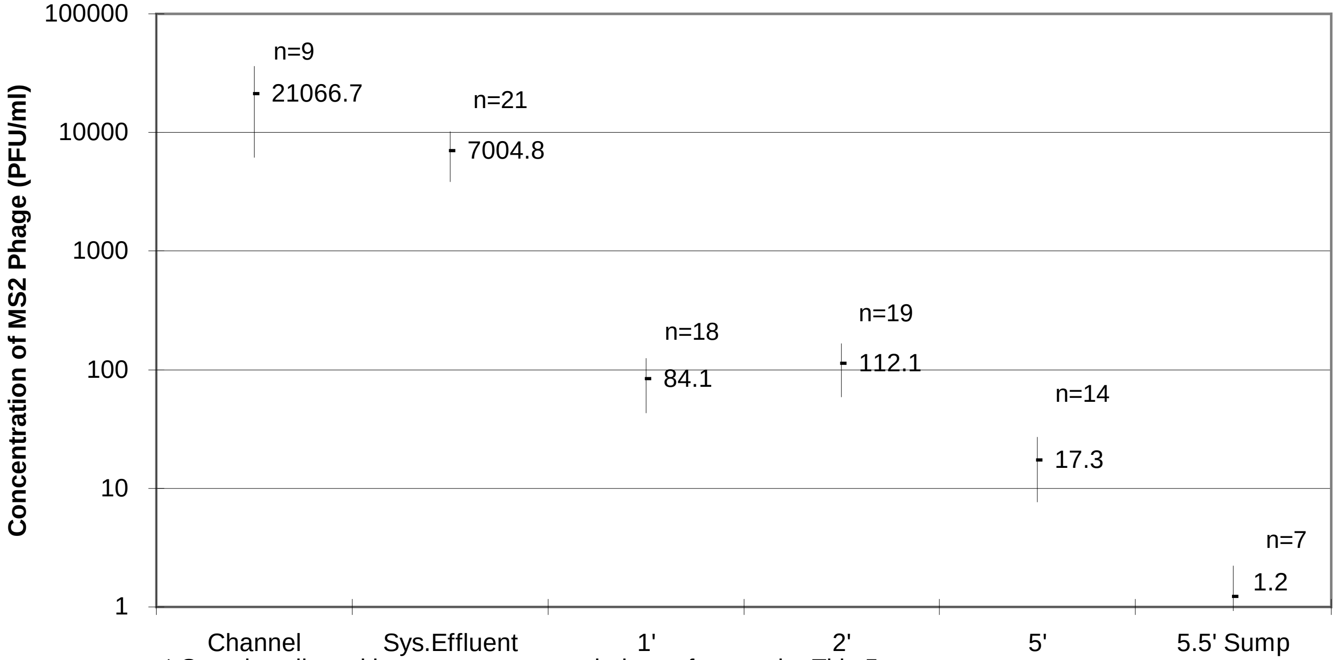
Levels of MS2 coliphage decreased as the wastewater progressed through the various treatment components within the standard onsite septic system and leach field (Figure 3). With little exception (1' pan collector) MS2 levels tended to decline several fold with each successive treatment stage. Reductions across the septic tank were significant (≈ 67%) and compared well with results of Payment et al. (1986) who found a 75% reduction in enteric viruses with primary settling, such as would occur in a septic tank. Similarly, a range of 24-83% virus removal during primary settling has been reported by Roa et al. (1981). Viruses are rarely free and isolated in the environment, but tend to be in aggregate form or linked with organic matter or suspended solids. In addition to biological digestion, the purpose of the septic tank is to allow time for suspended solids to settle. Monitoring of influent and effluent to the septic tanks at the study site shows a 30-50% removal of the suspended solids. It is likely that sedimentation plays an important role in the observed level of virus removal in these systems.

Figure 2.
Mean Density of MS2 Phage Virus in Influent to a standard septic tank assayed using an Ampicillin-resistant *Escherichia coli* host (Mean and 2SE).



Passage of the septic tank effluent through the leaching field provided a further 99.8% reduction in levels of MS2 coliphage most occurring within the first 30.5 cm (1 ft) of soil passage (and biofilm within the leach trench). At present it is unclear why there was not a decrease between the 30.5 cm and 61 cm depths in all three replicate test systems. However, the observed removal rate within the 61 cm soil column (.063-0.126 log_{10} per cm of soil passage) compares with observations of Butler et al. (1954) (as cited in Yates 1987) who reported a .051 $log_{10)}$ per cm of passage through sandy soil at comparable loading rates. Combining the observations taken at the 1 ft and 2 ft pan collectors indicates that 99.5% of the wastewater influent virus level is attenuated by the processes operating within the septic tank, leach trench and initial 2 feet of soil.

Figure 3.
Mean Density of MS2 Phage Virus assayed using an Ampicillin-resistant *Escherichia col*i host at selected locations within a standard septic tank and leachfield septic system treating residential wastewater (Mean and 2SE; dilution corrected based on specific conductivity).



* Sample collected in sump represents drainage from entire Title 5 system

The removal of virus particles with passage through the sand beneath the leaching trenches likely results from the concurrent removal of suspended organic matter with adsorbed virus load through the filtering process. Actual filtering of the unadsorbed viruses is unlikely since the critical pore space for medium sand (effective size 0.5 mm – critical pore size .072 mm) exceeds 1,000 times the diameter of the virus (0.00002 - 0.00003 mm). This would allow or easy passage of single unadsorbed viruses. However, sorption by the soil matrix of non-particle attached viruses is possible particularly in soils containing moderate amounts of clay minerals.

Data from samples taken 152 cm (5ft) beneath the leaching trenches suggested that, although virus removal increased with increased soil passage, the efficiency of removal declined. This is based upon the 99.8% removal of MS2 coliphage from the septic tank effluent to the 2’ soil depth, but only an 83% removal between the 61 cm (2 ft) and 152 cm (5 ft) soil depths. Diminished removal capability may be related to the attachment of MS2 coliphage to very small particles which are transportable through the soil matrix. It should be noted that the number of MS2 coliphage reaching the 152 cm (5 ft) soil depth represents a whole system removal efficiency of >99.9%.

Analysis of the MS2 coliphage levels can also be conducted on a transport time basis. We have not yet completed tracer studies to determine the mean time of passage of wastewater through the various components of the standard onsite septic system. However, based upon loading rates, system volumes and characteristics of the leaching field a time course was constructed. The time of passage was used to determine an average "decay" or "removal" constant for the whole system or 0.5 d^{-1}. The relatively short travel time <14 days supports the contention that the primary virus removal mechanism is sedimentation/filtration.

Collectively, the data suggests that the Massachusetts regulations requiring a five-foot vertical separation between the bottom of the leaching system and groundwater (for sandy soils with a percolation rate of < 2 minutes per inch) provides for over a 3 $\log_{10}$ or 99.9% removal of viruses at the allowable loading rate (3 cm/day or 0.74 gal/sq ft/day).

One of the goals of these experiments is to enable Public Health officials to determine the degree to which alternative onsite septic system technologies "compensate" for soil removal of pathogens. For reasons of both cost and that some regions do not have sufficient depth to the groundwater table, many manufacturers of I/A systems seek "credits" that will allow a decreased vertical separation to groundwater when their system is used. For instance, if a particular unit is shown to consistently remove 99.8% of human pathogens, this might compensate for 2 ft of soil passage (assuming similar soil type and hydraulic loading rate) and only a 3 ft soil column would be used. This might, in some instances, obviate the need for a more costly or obtrusive mounded system at some locations. However, ultimately it is the total virus level which remains which will guide public health considerations.

Very preliminary results of MS2 phage removal rates of different technologies are presented in Table 1. The results suggest the eventual promise that some reduction in vertical separation may be attainable with some technologies in cases where pathogens are the only concern. We must stress that the approach for establishing reduced separation distances needs to include a variety of virus and soil types and conditions and that the data presented below are preliminary. Also, a number of factors that control the persistence and entrainment of viral pathogens require further research. However, it is clear that some I/A technologies tested (activated sludge, recirculating sand filter) are approaching measured soil removal rates for MS2 coliphage (Table 1).

Table 1

Preliminary Results of Virus Reduction Rates from Septic Tank Effluent to System Effluent

Alternative Septic System	Percent Reduction of MS2 Virus
Open-Cell Foam Trickling Filter	32-62
Layered Sand Filter	78
Activated Sludge Treatment System	95
Recirculating Sand Filter (Immature Biomat)	98
Recirculating Sand Filter (Mature Biomat)	99

Yates (1987) has summarized compelling research indicating that virus removal in soils is inversely related to the hydraulic loading rate. Thus, any distance-to-groundwater credits awarded an alternative technology should not be coupled with concurrent allowances for reduced leachfield size, since reduced size translates to a higher hydraulic loading rate. In addition, since the effluent from many alternative technologies has a lower biological strength, a slower formation of a biomat in the leaching facility might be expected. It is likely that the large reduction in MS2 coliphage observed between the tank effluent and the 1 ft depth is in part due to the biomat associated with the leaching trench. Research is needed to show whether impeded formation of the biomat, resulting from pretreatment by I/A technologies, appreciably affects the ability of the leaching facility to remove viruses. As a conservative measure, alternative septic systems installed in remedial situations in Massachusetts may receive either vertical-separation-to groundwater relief or a reduction in leachfield size must use pressure distribution for effluent disposal in order to ensure that even hydraulic loading rate occurs across the infiltrative surface. This measure likely maximizes the treatment for pathogenic viruses.

SUMMARY

The data presented indicate that the standard 5678 l (1500 gal) septic tank receiving 330 gal/day removes approximately 67% of the viruses. Presumably, this reduction in viruses is due to their association with organic particles that are settled out in the septic tank. The leach trench receiving effluent at 3 cm/day (0.74 gal/sq ft/day) and placed in medium sand fill removes an additional 99.9% of the surrogate virus in a passage of 152.5 cm (5 ft). Of the alternative septic systems tested, a recirculating sand filter with a mature biological surface appears to offer the best treatment for viruses and compensates for approximately 61 cm (2 ft) of soil passage, based on the MS2 coliphage studies. Further studies to be conducted at the Massachusetts Alternative Septic System Test Center will include evaluation of mechanisms of virus removal and processes controlling removal rates under standard and high loadings. These studies and those of other groups are needed to produce the science-based rationale for establishing separation-to-groundwater and leachfield reduction "credits" for each alternative septic system technology while still addressing public health concerns.

REFERENCES

Butler, R.G., G.T. Orlob, and P.H. McGauhey. 1954. Underground movement of bacterial and chemical pollutants. ***J. Amer. Water Works Assoc***. 46:97-111.

Payment, P., S. Fortin, and M. Trudel. 1986. Elimination of human enteric viruses during conventional wastewater treatment by activated sludge. ***Can. J. Microbiol***. 32:922-925.

Rao, V.C., S.B. Lakhe, S.V. Waghmare, and V. Raman. 1981. Virus removal in primary settling of raw sewage. ***J. Environ. Eng., Div. Am. Soc. Civ. Eng***. 107:57-59.

Yates, M. V. 1987. Septic Tank Siting to Minimize the Contamination of Ground Water Microorganisms. USEPA . Office of Ground-Water Protection. 87 pp.

COMPARISON OF STANDARD SEPTIC TANK-LEACH TRENCH SEPTIC SYSTEMS WITH TWO ENHANCED-TREATMENT SEPTIC SYSTEMS FOR ATTENUATION OF MS2 COLIPHAGE

Sean Foss[1], John Higgins[2] and Beth Berstene[3]

INTRODUCTION

The Alternative Septic System Test Center (ASSTC) located at the Otis Air National Guard Base in Sandwich, Massachusetts is a collaborative undertaking involving the Buzzards Bay Project, the Barnstable County Department of Health and the Environment, the University of Massachusetts Center for Marine Science and Technology, and the Massachusetts Department of Environmental Protection (MADEP). Designed to assess the efficiency of alternative and innovative (I/A) onsite wastewater treatment technologies, the Test Center currently receives the major portion of its operating budget from the MADEP as part of its initiative to identify and permit promising onsite septic system technologies. The Test Center is also testing four technologies under the Environmental Protection Agency- National Sanitation Foundation Environmental Technology Verification Program (ETV).

As part of its mission, the Test Center began investigations relative to the pathogen removal performance of systems undergoing nitrogen testing. It is reasoned that, the relatively “clear” effluent typical of many denitrifying units being tested at the Center might challenge the receiving soils with pathogens while not concurrently providing for growth of a biological mat or unsaturated flow at point of discharge (in gravity-fed soil absorption systems). These features are is generally believed necessary for pathogen removal. Additionally, Massachusetts’ regulations require that any alternative treatment systems must prove that they provide an equal degree of environmental protection as is

[1] Barnstable County Department of Health and the Environment, Superior Courthouse, Route 6A, Barnstable, Massachusetts 02630
[2] Massachusetts Department of Environmental Protection Training Center, 50 Route 20, Millbury, Massachusetts 01527
[3] Barnstable County Department of Health and the Environment, Superior Courthouse, Route 6A, Barnstable, Massachusetts 02630

afforded by a standard septic tank-soil absorption system. Health officials were concerned that the pathogen issue might not be adequately addressed.

In 2000 (Higgins et. al. 1999, 2000), we reported on the attenuation of viruses in triplicate septic tank-leachfield systems using background levels of 10^4 PFU/ml MS2 coliphage as a surrogate indicator of pathogenic viruses. The purpose of those studies was to establish the level of protection from pathogens that is afforded by a “standard” system. The purpose of the present study is to corroborate past findings involving a standard septic tank-leach trench system and compare these results with treatment by two alternative septic systems, the Waterloo Biofilter® a trickling filter system and the F.A.S.T® a fixed activated sludge treatment system that are challenged with known levels of viruses.

METHODS AND MATERIALS

In this study, two approaches were first undertaken to verify previous results for the standard septic system. First, “steady state” tests were performed by adding known quantities of viruses for a period of time that was considered necessary to induce steady state conditions in the distribution box following the septic tank, and in the receiving soils. These tests, conducted in March-April 2000, maintained inputs to the septic tank that resulted in levels of 10^5 PFU/ml at the distribution box for 2 weeks. Monitoring at the distribution box and pan lysimeters beneath the leaching trenches was conducted for an additional 4 weeks. To avoid the problems associated with the handling of pathogenic viruses, a surrogate virus, MS2 male-specific coliphage, was chosen because it is innocuous and approximately the same size and shape as pathogenic animal viruses commonly found in wastewater. Methods of detection were previously described (Higgins et. al. 2000).

Three standard systems were tested. The systems each include a 5678 l (1500 gal.) single-compartment septic tank, a Dipper™ distribution box, and a leaching trench with bottom and side dimensions of 0.6 m (2 ft.). The hydraulic loading rate is set for 3 cm/day (0.74 gal/sq ft/day). Calibrations of dosing rates occurred monthly. Testing locations include septic tank effluent, pan collection devices located at elevations of 1’, 2’ and 5’ beneath the leaching trench, and in the sump underdraining the leaching facilities at an elevation 5.5’ below the leaching trenches (Figure 1).

Following the steady state experiments, “slug” tests were performed both on the standard septic systems and two alternative septic system technologies, the Waterloo Biofilter and the F.A.S.T system. During slug experiments, a titer of virus, and for the standard septic system a volume of bromide tracer, was added to each septic tank to cause resulting levels of $10^{4.5}$- 10^{6} PFU /ml MS2 (and 80-100 mg/l bromide tracer in the case of the standard septic system). Measurements of these parameters were subsequently conducted for 17 days for the standard septic system and 14 days for the alternative septic system units. All systems were dosed with 330 gallons per day over 15 equal doses.

Waterloo Biofilter® System

The Waterloo Biofilter used in this study was configured as a single-pass filter situated between the septic tank and the leachfield. Flow proceeds from the 1500-gallon septic tank to a 50-gallon pump chamber (Figure 2). The effluent is distributed under pressure to the top of the media bed. The media, which is 2” x 2” open-cell foam is contained in a 8’ x 4’ x 4’ closed container. The effluent/filtrate drains to the leaching facility by gravity. Ventilation of the system is achieved by 3” vents on the sides of the unit fitted with activated charcoal filters.

MicroF.A.S.T. ® System

The MicroF.A.S.T. system consists of a baffled septic tank where the first compartment is 500-gallon capacity and the second compartment is 1000-gallon capacity. The second chamber contains a submerged media bed fixed in position near the discharge end of the tank (Figure 3.). An air blower located above-ground continuously supplies air down a central tube to the bottom of the submerged media at about 200 cubic feet of air per minute. Wastewater enters the first chamber, where primary settling takes place. Passing through a central baffle, the wastewater entering the second chamber is airlifted through the media bed. A portion of the airlifted wastewater is returned via a return tube to the primary settling chamber and a portion exits the tank at the discharge end.

RESULTS AND DISCUSSION

Only standard septic tank-leach trench system #1 yielded consistent samples from the 1-ft and 2-ft. lysimeters, although the sporadic results from the other trench systems do yield useful information (Figure 4) for the steady-state experiments. Combined, the results indicate a 1-2 log (90-99%) reduction within the first 2 feet of soil passage, when the soil absorption system is challenged with virus densities of 10^5 PFU/ml. The few exceptions to this trend are exhibited in data from system #2 and system #3 (where little or no attenuation of viruses is periodically observed). In these lysimeters the recovery volumes of sample from the lysimeters was inconsistent and suggested that steady-state flow patterns beneath these trenches was disrupted and/or not yet established. A considerably more erratic pattern of virus removal is indicated at the one-foot depth, suggesting that in our trenches this stratum was particularly unstable zone in relation to the establishment of flow patterns. Data from the sump that collects from all three-trench systems at a depth of 5.5 ft (Figure 5) indicates that with few exceptions there is a 1.5-2-log reduction in viruses. This result is somewhat unexpected and suggests very little attenuation compared to two feet of soil passage discussed above. It is unfortunate that no consistent collections were obtained from the 5-ft lysimeters to corroborate this finding.

The consistency in lysimeter sample volumes during the September 2000 slug tests suggested that only standard System #1 was appropriate for the test. These data (Fig.6) indicate a fairly consistent 2-log+ removal (99%) of virus following two feet of soil passage. These data closely agree with attenuation rates previously observed (Higgins et al. 1999,2000). Removal of viruses after one ft. of passage ranged from little or no removal at the higher influent densities (10^5 PFU/ml), to a 1+ log removal (90%+) removal rates at densities below 10^4 PFU/ml indicating that the overall percentage reduction is related to the magnitude of the challenge. This trend, although not as obvious, was also observed for the 2-ft lysimeters. Collectively the data indicate that greater challenges to the soil system resulted in less removal efficiency. Of interest in these slug experiments was the fact that following the introduction of the high titer of viruses on September 11, 2000, the one-ft lysimeter demonstrated its peak value two days later, and the two-ft lysimeter demonstrated a peak level three days later on September 14th. The lack of correspondence of the virus peak density with the peak bromide concentration at the 1-ft. lysimeter may be explained by the sampling interval (Figure 7.). We believe that due to the relatively long intervals between sampling events, we may have missed the bromide tracer peak in the1-ft lysimeter.

The reasons for the lower variability in virus attenuation during the September 2000 slug tests compared with the previous April-May steady-state experiments can only be speculated. It may be that the biomat formation in September had reached a point where it supported more uniform unsaturated flow beneath the soil absorption system. The sporadic low attenuation observed during the April-May tests do suggest that during some of the sampling periods there was preferential flow in the area of the lysimeters (hence possibly indicating an immature biomat).

Collectively the data from both the steady-state and slug tests agree with data previously presented (Higgins et al., 2000) with some exceptions. Foremost, the present studies indicate a higher degree of variability in the removal efficiency of 1-ft of sand. In some instances, no attenuation of viruses was noted at this depth. While this phenomena was also observed for the 2-ft depth of sand, it was not as common.

Data from the three replicates during the steady-state portion of this study strongly suggest a cautious approach to predicting removal efficiencies. The pan lysimeters at each replicate were highly variable in their performance (ability to collect a sample) among replicates and among sampling dates. This variability is likely due the highly variable rate of biomat formation, its periodic disruption and reformation, and the non-uniform preferential downward flow that these conditions impart. It was decided that data from sample volumes less than 50 ml would not be included in our analysis, since these volumes suggested an inadequate recharge of the lysimeter and dilution with condensation from the sides of the riser pipe would be significant. Sample volumes ranged from 5-4000 ml. Again this variable sample volume suggests that there is differential flow across the bottom area of the leach trenches that prevents accurate prediction of virus attenuation until, perhaps a stable biomat forms that will allow an even unsaturated flow beneath the soil absorption system.

Commonwealth of Massachusetts approvals for many alternative septic systems allow for the soil absorption system to be situated 2 ft vertically closer to the water table than systems without these treatment units. These approvals have been made in the past without benefit of the understanding of the pathogen reduction "credit" of either the soil beneath the soil absorption system or the treatment unit itself. This portion of the study suggests that the two-foot relief from the required vertical separation should only be granted it a 2-log reduction of viruses is achieved prior to discharge.

Tests of Alternative Technologies

Results from slug experiments of the two enhanced treatment systems, the Waterloo Biofilter® and the F.A.S.T® treatment system, show that both the extent of virus attenuation and the mechanisms for attenuation differ considerably.The attenuation of viruses in the Waterloo Biofilter was variable and ranged from 0.5-log reduction during the initial three days of the challenge, to a 1-2 log reduction in the days following this initial period. Within each day, there was commonly a 0.5 log variability in the removal rates. A closer inspection of the data suggests a reason for this within-day variability. The dosing pattern to each system at the Test Center is 15 equal doses at 0600 hr, 0700 hr, 0730 hr, 0800 hr, 0900 hr, 1100 hr, 1200 hr, 1300 hr, 1400 hr, 1700 hr, 1730 hr, 1800 hr, 1900 hr, 1930 hr. and 2000 hr. Sample times during this study were chosen necessarily based on available time between other Center Tasks. As can be seen from the dosing schedule, the 1100 hr, 1700 hr and 0600 hr doses are preceded by at least a two-hour period where no dosing takes place and presumably the filter becomes less saturated as it drains. In nearly every day in which multiple samples were taken at different times, the lowest virus levels in the effluent corresponded to sampling following the 1100 hr or 1700 hr dose (no samples were taken at the 0600 hr dose for any day). Conversely, the highest virus levels were observed during the 0900 dose which is preceded by the 0600hr, 0700hr, and 0800hr doses (Table 1). This strongly suggests that the saturation state of the filter material affects removal efficiency for viruses, with the less saturated condition being more conducive to higher removal rates. The overall reduction of viruses in the septic tank of the Waterloo system over the 14 days of measurements likely reflects only reductions due to the dilution as opposed to inactivation. The projected virus density trendline in Figure 8 was based on a simple dilution model and parallels a trendline through the actual virus densities observed. We believe that exact correspondence is precluded by the variability induced by dosing volume (± 10%), sample variability (estimated ± 10%), and analytical variability (estimated ± 10%). Alternately however, exact correspondence of observed values and projected values based on dilution may be due some limited replication of MS2 in the septic tank during this period. The later hypothesis is challenged by the generally accepted belief that MS2 phage do not replicate at the temperatures (<15 C) observed. In any event, it is clear that there are no inherent qualities of the incoming wastewater that appear to be destructive to MS2 phage. This is an important assumption in the following discussion of results from the F.A.S.T. unit.

Table 1. Dosing time exhibiting the highest daily virus density for the Waterloo Biofilter® at the Massachusetts Alternative Septic System Test Center from November 6 – 19, 2001. Emphasized dosing periods are preceded by successive doses at 1hour intervals. Other doses are preceded by a non-dosing period of at least 2 hours.

Date	Dose Exhibiting Highest Density of Virus	Number of Doses Sampled
6-Nov	11:00	4
7-Nov	**7:00**	4
8-Nov	**9:00**	3
9-Nov	**9:00**	2
10-Nov	**9:00**	2
11-Nov	**9:00**	3
12-Nov	**9:00**	2
13-Nov	**9:00**	2
16-Nov	**9:00**	2
18-Nov	17:00	2
19-Nov	**9:00**	2

Results from the MicroF.A.S.T treatment system suggest a considerable difference in both the degree of treatment and the mechanism of attenuation. Figure 9 again contrasts the results from the septic tank with that of treated effluent. The near correspondence between the septic tank and the effluent is apparently the result of the mixing within the two-compartment tank. Again, the expected reductions in the septic tank are projected based on a simple dilution (330/1500 or 22% per day). The difference between this expected density of viruses and the observed levels in both the septic tank and the effluent, is the overall virus reduction of the system. The data suggests that the overall reduction of viruses in this system will depend on residence time in the system itself.

Unfortunately, the apparent extent of mixing within the F.A.S.T. system itself confounds our ability to assign an accurate virus removal benefit for the F.A.S.T. This can be illustrated by example. When initializing the experiment, we introduced the virus titer into the first compartment of the septic tank during the 0900 hr dose and mixed the compartment moderately but not such that we would resuspend settled solids. After two hours, we sampled the system during a dosing cycle (1100 hr). At that time the approximate difference between the effluent and the septic tank was 0.5 log (approximately 30%). Since no additional viruses were added to the system, the environment in the system continued to inactivate viruses at a rate dependent on the average residence time in the tank. Accordingly after 2 days the effluent virus densities were reduced by approximately 1 log (90%), after 6 days there was a 2-log or 99% reduction, and after 6 days, there was over a 3-log or 99.9% reduction. These reductions are estimated based on expected levels of virus due to simple dilution. The reader can recall that the “control” or standard septic tank (data derived from the Waterloo septic tank which is not intermixed with treated effluent and can therefore be considered exhibiting a pattern of virus reduction control for comparison purposes) only exhibits dilution reductions (Figure 8).

The data indicate that overall the virus removal in the MicroF.A.S.T. will be highly dependent on the residence time of the viruses in the system itself. High virus loading accompanied by low hydraulic loading will result in higher retention times and more virus removal. The MicroF.A.S.T. in our study was supplied influent near its design loading for Massachusetts (when configured for denitrification). In this scenario it appears that there is approximately a 30% reduction in viruses, however even this value depends on the loading patterns during the day. Should the hydraulic loading be less, greater virus attenuation can be expected, however due to the complete mixing of this system, only average residence times can be calculated. These values are inappropriate to use for virus level prediction since the uniform mixing of the viruses in each batch of incoming wastewater can not be confirmed.

Conclusions

This study was initiated, in part, to clarify the relative treatment of a standard septic tank-leach trench system, including 5 ft. of soil passage, for viruses compared with alternative septic system technologies' treatment for viruses without the soil system. The study is the first step in determining whether pretreatment of septic tank effluent (STE) should be allowed to substitute for any portion of the soil system. Presently in Massachusetts, selected alternative septic system technologies allow an applicant to substitute for 2 ft. of vertical separation to groundwater or 50% of a soil absorption system size (infiltrative surface).

Our data suggests that neither of the two systems tested compare with a standard septic-tank leachfield for virus attenuation *by themselves (without a soil system).* This information raises the question as to whether pretreatment of septic tank effluent accompanied by a soil absorption system offers the same degree of pathogen removal as a standard septic tank-leach trench system. Some authors (Van Cuyk and Siegrist, 2001) have indicated that the state of knowledge in this area is not adequate to answer the question. These authors point to the range of studies that underscore the importance of the clogging layer in removing viruses and bacterial pathogens and the dearth of information on the genesis of the biomat in systems using pretreatment. They suggest that the regulatory reliefs that enable the substitution of pretreatment for vertical separation or soil absorption system size (=higher hydraulic loading rates) should expand their consideration beyond merely hydraulic efficacy. This concern should be heightened in areas of coarse sand where the removal of viruses is likely less due to decreased adsorption characteristics.

REFERENCES

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

Higgins, J., Heufelder, G, and S. Foss. 1999. Removal Efficiency of Standard Septic Tank and Leach Trench Septic Systems for MS2 Coliphage. Proc. 10th Northwest On-Site Wastewater Treatment Shortcourse. September 20-21, 1999, Univ. Washington, Seattle, WA. Pp. 81-88.

Van Cuyk, Sheila, and R. Siegrist. 2001. Pathogen Fate in Wastewater Soil Absorption Systems as Affected by Effluent Quality and Soil Clogging Genesis. In Mancl, K. ed. Proceedings of the Ninth National Symposium on Individual and Small Community Sewage Systems – March 11-14, 2001. Amer. Soc. Ag. Eng.

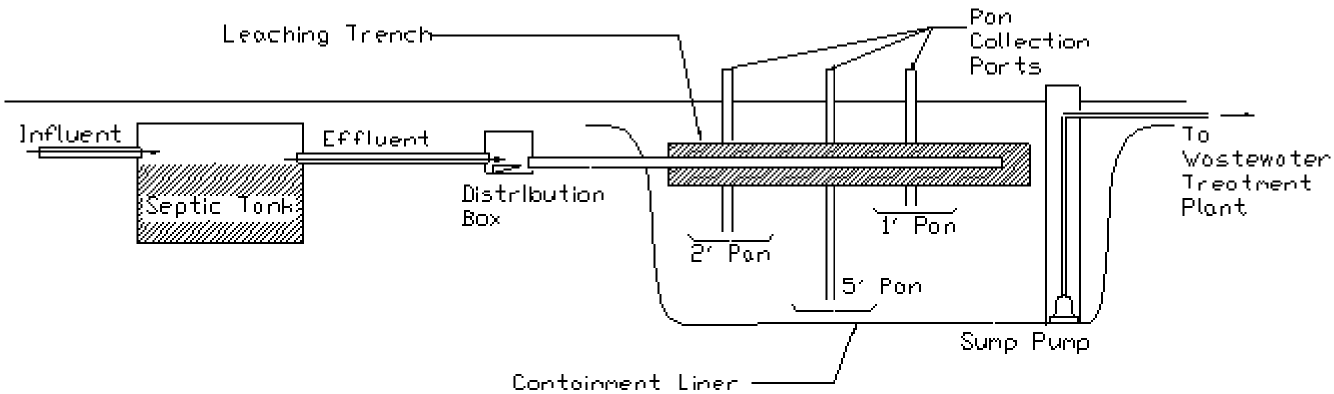


Figure 1. Profile of standard septic tank, distribution box, and leaching trench septic system design at the Massachusetts Alternative Septic System Test Center.

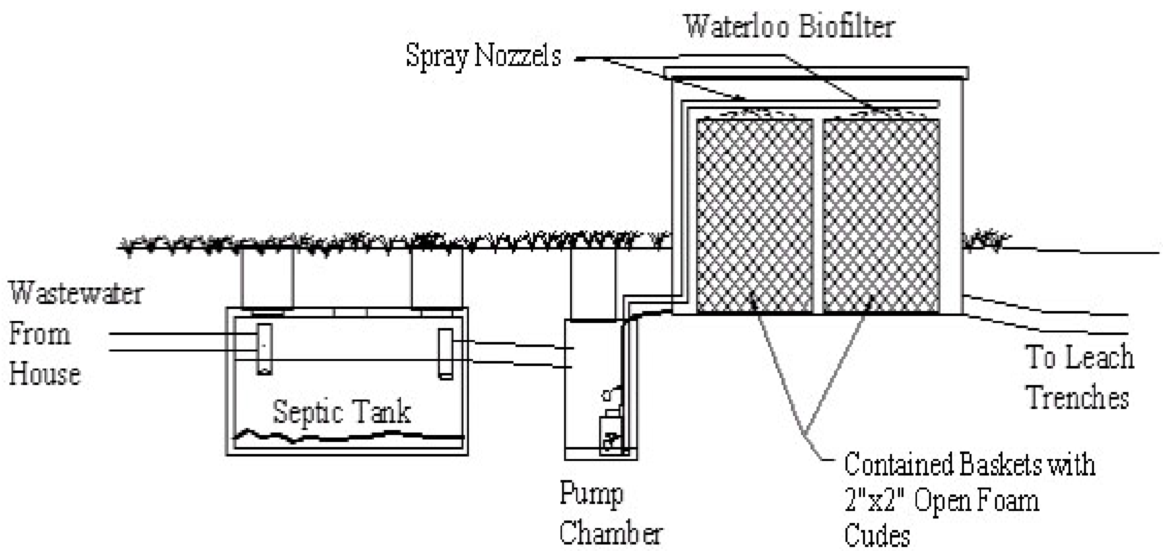


Figure 2. Profile of Waterloo Biofilter system at the Massachusetts Alternative Septic System Test Center.

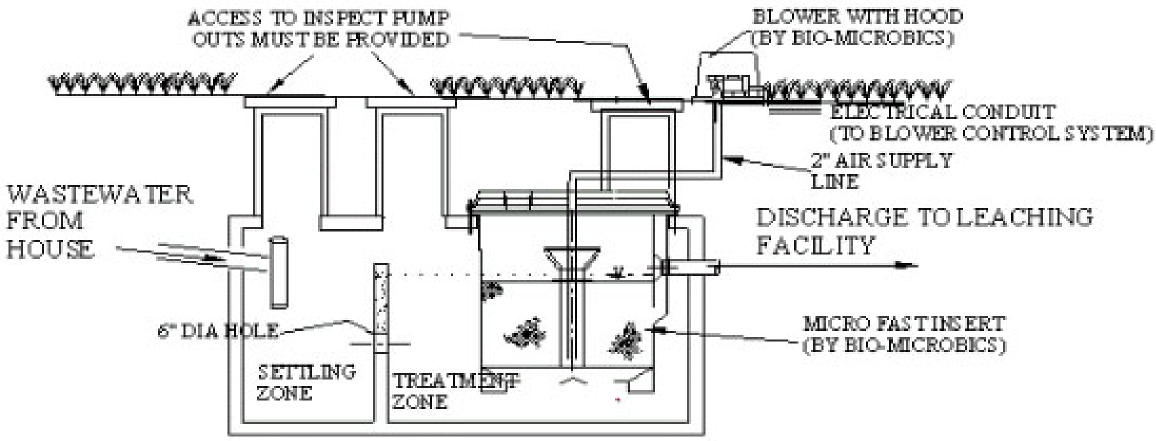


Figure 3. Profile of FAST system at the Massachusetts Alternative Septic System Test Center.

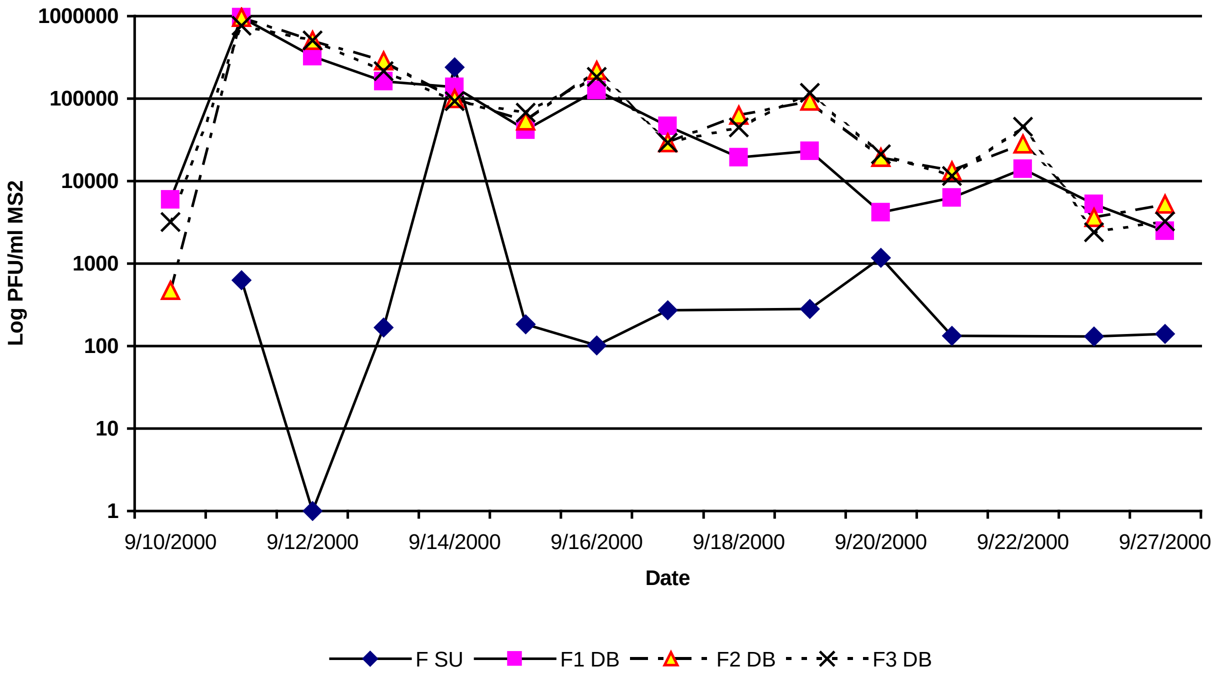


Figure 5. MS2 virus (PFU/ml) removal slug test for standard septic tank/leach trench systems 1 – 3 in the distribution boxes and sump at the Massachusetts Alternative Septic System Test Center from September 10 – September 27, 2000.

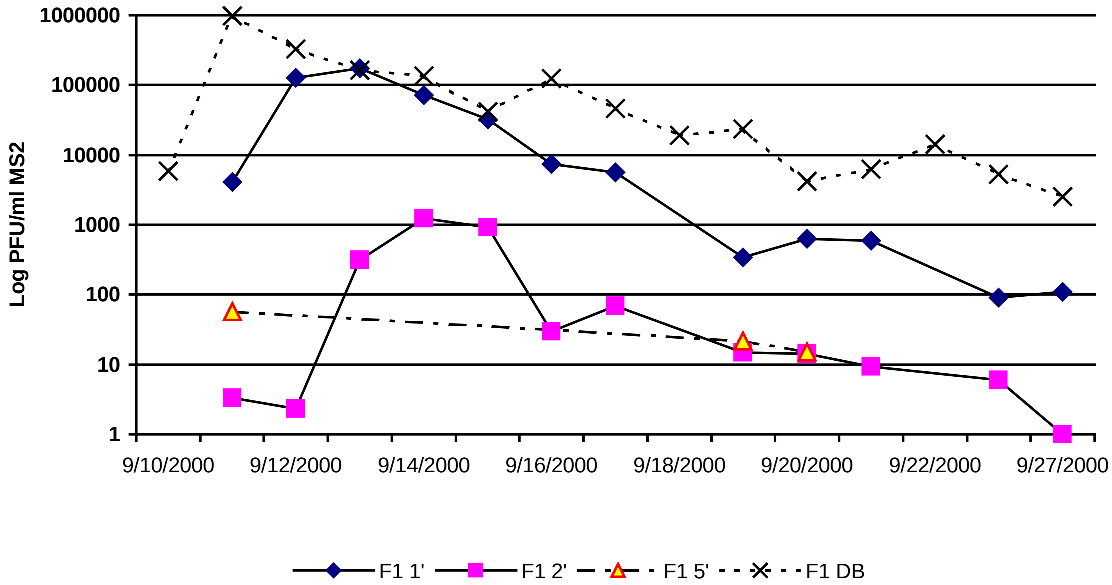


Figure 6. MS2 virus (PFU/ml) removal slug test for standard septic tank/leach trench systems 1–3 in the distribution boxes and lysimeters at the Massachusetts Alternative Septic System Test Center from September 10 – September 27, 2000.

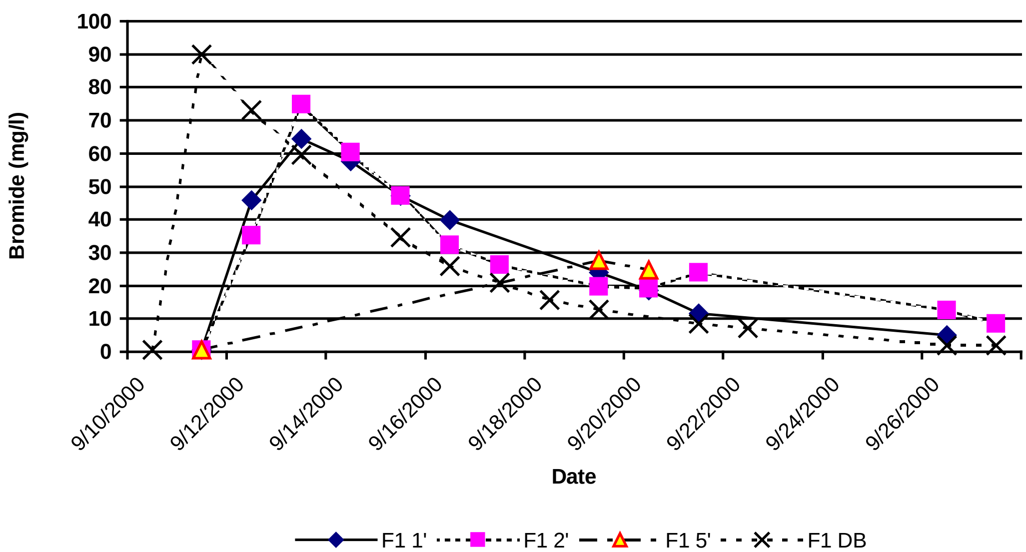
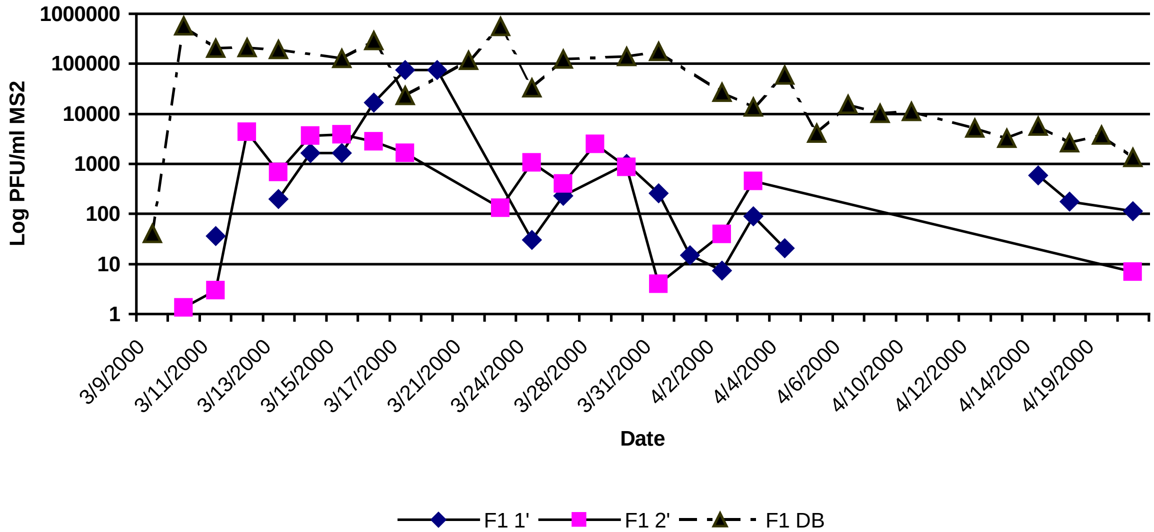
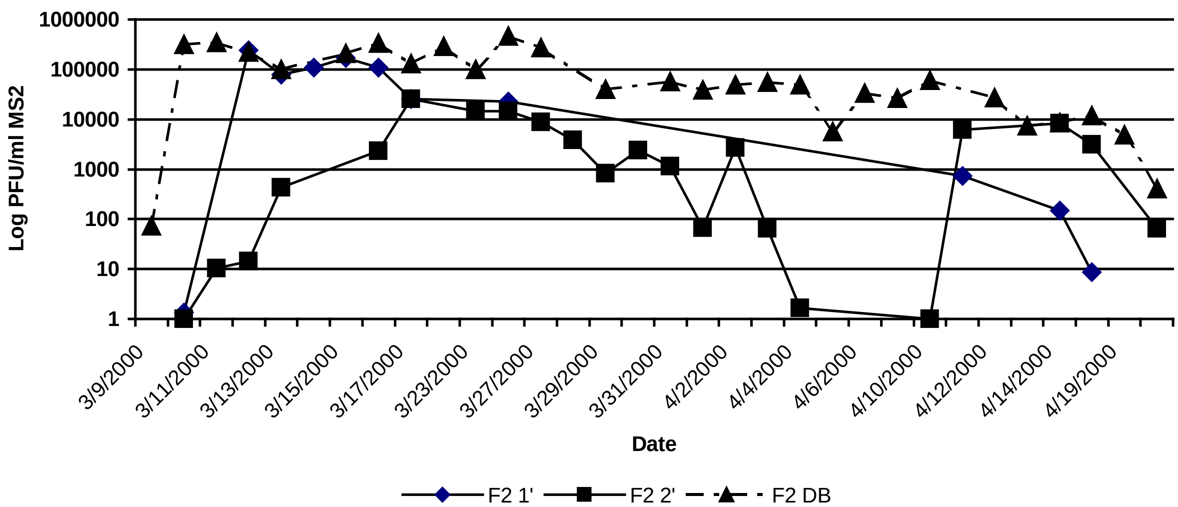


Figure 7. Sodium bromide (mg/l) slug test for standard septic tank/leach trench system 1 in the distribution box and lysimeters at the Massachusetts Alternative Septic System Test Center from September 10 – September 27, 2000.





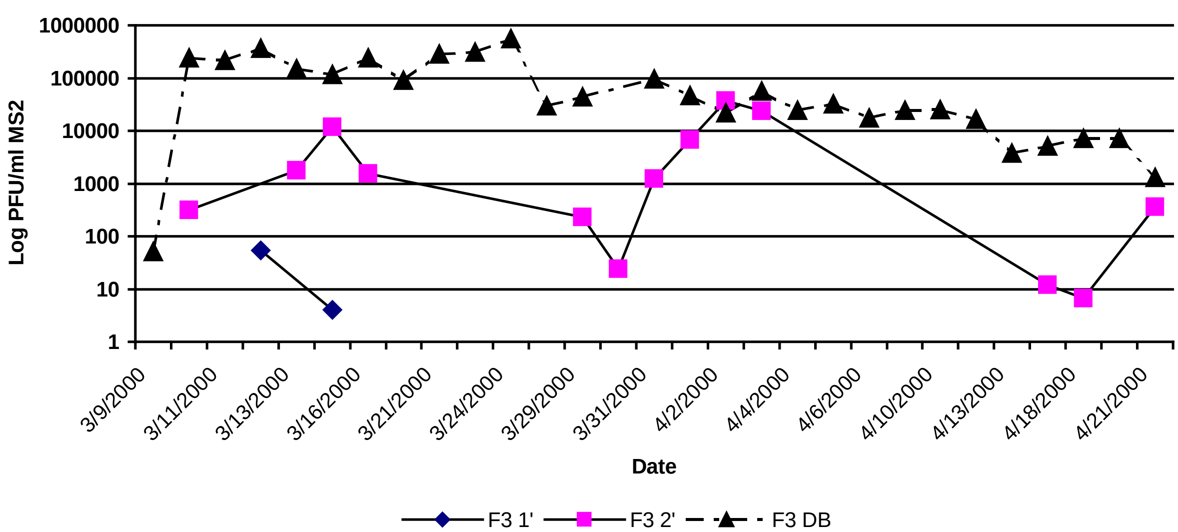


Figure 4. MS2 virus (PFU/ml) removal steady state test for standard septic tank/leach trench systems 1 – 3 in the distribution boxes and lysimeters at the Massachusetts Alternative Septic System Test Center from March 9 – April 21, 2000.