RULE DEVELOPMENT COMMITTEE ISSUE RESEARCH REPORT
DRAFT
- DISPOSAL TREATMENT OPTIONS:
HIGHLY PRETREATED EFFLUENT -

DOH Staff Researchers:	Selden Hall
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Topic & Issues:

DISPOSAL COMPONENT REDUCTIONS – PATHWAY NUMBER 1

(HIGHLY PRETREATED EFFLUENT)

- Address how size reductions are applied. The limitations to these sizing reductions should apply to all technologies for which an absorption area is proposed.
- When allowing reduction in installed drainfield, should 100% available primary and reserve area set aside be required in rule?
- There is an allowance for 50% reductions in installed drainfield size when using enhanced treatment. Should there be an allowance for additional reductions due to disposal component reduction allowance?

The following set of questions has been developed to address the issues stated in the Topics & Issues above. DOH would like the TRC to answer/ render decisions on questions 4-9.

1. Where are we now with disposal component reductions based on highly pretreated wastewater? *[50% reduction allowed with 10/10 800 effluent – See Table 1, Effluent Quality Based Drainfields]*
2. Why are drainfield component reductions used?
3. Should we continue to define highly pretreated wastewater as 10/10 (no fecal coliform requirement)?
    a. If no, how should it be defined?
4. What does the scientific literature say about the hydraulic and treatment performance, and longevity of drainfields loaded with highly pretreated wastewater?
5. Based on the literature review, should reductions for highly pretreated wastewater be allowed?
6. If reductions are allowed:
    a. What should the reductions allowances be?
    b. Should 100% primary and reserve absorption areas be required?
    c. Should O&M be required?

7. When reductions are allowed for pathway 1, should additional reductions due to pathway 2 be allowed (Increasing the loading rate even further.)?
8. If a reduction is taken for drainfield sizing based on highly pretreated wastewater, can a reduction to VS be also allowed for this same highly pretreated wastewater?
9. What methods of distribution should be allowed when highly pretreated effluent is discharged to the SSAS?

Summary:

Of the two pathways currently available for applying reductions in absorption area ([1] highly pretreated effluent and [2] special features and application of alternative drainfield products), this literature review is focused on first pathway. The second pathway, reductions for alternative drainfield products, will be the subject of a separate literature review.

The following documents were included in the review: 19 journal articles, 31 conference proceedings papers, 2 government reports, 1 NSFC report and 1 master's thesis.

When research on on-site sewage systems began in the mid-20th Century, there were two schools of thought on the declining absorption rate over time. One school believed that ultimately, the absorption rate would eventually decline to zero. The other school acknowledged the steep decline in absorption rate but asserts that an equilibrium would be achieved. After 50 years of work, the overwhelming majority of researchers conclude that soil absorption systems can reach a long-term acceptance rate. This long-term acceptance rate is a function of the clogging of soil pores at the soil interface upon which the wastewater is applied. The main factors in clogging are the loading rate to the soil and quality of the wastewater. Hydraulic loading rates can be significantly increased for high quality wastewater relative to septic tank effluent. Wastewater quality should be one of the design factors for soil absorption systems. Increasing the pretreatment of domestic wastewater prior to soil application increases the service time, perhaps indefinitely, of the soil surface. Soil clogging can be delayed or altogether mitigated by reducing the applied mass loading rates of BOD and TSS. Some researchers caution about allowing increased loading rates (reduced absorption areas) based on the ability of the soil to accept the higher hydraulic loading. The clogging mat is the most efficient part of the system in terms of removing bacteria and viruses. Increased loading rates and elevated fecal coliform counts will yield fecal coliforms deeper in the soil profile. One paper concludes that there is a need for a fundamental understanding of the fate and transport of pathogens in SSAS before increasing the loading rates to soil, based on high levels of pretreatment. Another paper cautions against coupling a reduction in vertical separation and reduction in drainfield size when applying highly pretreated effluent to the soil component. In contrast, another study that monitored groundwater down gradient of a subdivision and down gradient of individual soil absorption systems found that enteroviruses are routinely found in domestic sewage entering septic tanks, they survive in septic tanks for up to 60 days, and small numbers can be found immediately beneath the infiltrative surface. However, they found no virus 10 feet down gradient of the OSS, and found no virus but elevated nitrates down gradient of the subdivision.

Highly pretreated effluent allows for discharge to subsurface infiltration systems at hydraulic loading rates in excess of those utilized for domestic septic tank effluent without stimulating soil clogging. However, without the clogging mat, the fate of pathogens is not well understood. Despite one researcher's findings that suggest that virus transport is not occurring down gradient from soil absorption systems, increasing loading rates solely based on hydraulic performance may not be prudent at this time. Furthermore, since virus removal in soils is inversely proportional to the hydraulic loading rates, coupling reduced vertical separation with increased loading rates is cautioned against.

KEYWORDS: Soil Loading Rates, Infiltration Rates, Wastewater Infiltration, Soil Clogging, Soil Hydraulic Capacity, Soil Absorption, Infiltration Capacity,

Introduction:

In Washington state, loading rates to the soil absorption system, and therefore the size of the absorption system, are determined by soil texture (WAC 246-272-11501). These loading rates assume a well-developed clogging mat, which greatly retards the infiltration rate into the native soil. There are two pathways to absorption area reductions, one based on highly pretreated effluent that eliminates or greatly retards the development of a clogging zone, and the other based on special features and application of alternative drainfield products. This literature review will address the first pathway: use of highly pretreated effluent. Currently, DOH has a Recommended Standards and Guidance for Effluent Quality-Based Drainfields. This RS&G describes the conditions of pretreatment where drainfield reductions (i.e. increased loading rates) might be applied. Reductions for alternative drainfield products will be the subject of a separate literature review.

The purpose of this review is to synthesize the literature available on the topic of drainfield size reductions based on highly pretreated wastewater so that the Technical Review Committee can make appropriate recommendations about loading rate requirements to the Rule Development Committee. Fifty-four 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 are by highly respected researchers in the on-site field.

Since increased loading rates are based on limiting or eliminating the clogging zone, this literature review will first describe the clogging zone and its relationship to absorption rates of effluent into the soil. Then it will report the observed consequences of limiting and / or eliminating the clogging zone. Finally, this review paper will draw some overall conclusions regarding absorption area reductions that are strongly supported in the scientific research literature. Out of these conclusions, the author of this review makes recommendations on the original questions about absorption area reductions.

Body:

CLOGGING ZONE AND ABSORPTION RATES

NATURE OF THE CLOGGING ZONE

The clogging zone, also known as the clogging mat, biomat and biocrust, forms at the infiltrative surface in drainfields receiving septic tank effluent. Early research investigated the phenomenon of reduced infiltration rates over time, which in most cases is only a small fraction of the saturated flow rates of a soil profile. The clogging zone is a surface phenomenon and may penetrate into the soil matrix for a few millimeters. The clogging material largely consists of suspended solids, bacterial growth, polysaccharides and polyuronides generated by the microorganisms, and some ferrous sulfide precipitate (McGauhey and Winneberger, 1964. Siegrist, 1987a, 1987b., Pell and Ljunggren, 1985. Otis 1984.) The preponderance of evidence is that this clogging is not irreversible (Kropf, Healy, Laak, 1975, Kropf, Laak, Healy 1977).

CAUSE OF CLOGGING ZONE

A number of researchers identified that BOD and TSS in the applied effluent are highly correlated with clogging zone development. Laak (1970, 1976), reports that the severity of clogging should be expressed in terms of TSS and BOD of the incoming liquid. Hargett, Tyler, Siegrist (1982) show that the loss of infiltrative capacity is related to the amount and frequency of wastewater applied over time. Siegrist (1987a, 1987b) further describes soil clogging development as highly correlated with cumulative mass density loadings of total biological oxygen demand and suspended solids and that wastewater quality and hydraulic loading rate are primary factors in soil clogging development.

IMPACT OF THE CLOGGING ZONE

One obvious consequence of a clogging zone is drastically reduced infiltration rates of applied wastewater (and therefore larger absorption areas), as noted by many researchers. The clogging zone also results in aerobic conditions below the clogged layer (Kristiansen, 1981). The clogging zone is where a great deal of the treatment occurs, including the removal of much of the BOD, TSS, bacteria and viruses (Van Cuyk, et al 2001).

CONTROL OF THE CLOGGING ZONE

The main factors in clogging zone development are BOD and TSS, and pretreatment can be used to manage and reduce the clogging mat. Removal of these constituents from domestic sewage reduces soil clogging and permits smaller seepage bed installations (Laak, 1974. Laak, 1976). Control of clogging also requires good site selection and design; narrow trenches are preferred over beds; intermittent dosing and resting will prolong the life of the infiltration system (Otis, 1984). Higher quality wastewater effluents can be discharged to subsurface infiltration systems at hydraulic rates in excess of those utilized for domestic septic tank effluent without stimulating soil clogging development (Siegrist, 1987a). Soil clogging can be delayed or altogether mitigated by reducing the applied mass loading rates of BOD and TSS (Siegrist and Boyle, 1987). Maintaining the wastewater infiltrative surface in the soil is dependent on never exceeding the design hydraulic or BOD and TSS loading rates (Tyler and Converse, 1994). Reducing organic materials with wastewater pretreatment systems reduces soil pore plugging (Tyler, Converse and Keys, 1995). Erickson and Tyler (2001) report that maintaining aerobic conditions at the infiltrative surface could substantially reduce or eliminate clogging. To maximize delivery of oxygen, soil components should be shallow, narrow and have separated infiltration areas. In other words, the system design must be long, thin and located close to the oxygen source.

AFFECTS OF LITTLE OR NO CLOGGING ZONE DEVELOPMENT

<u>Prolonging the life of the soil absorption component.</u>

In sand column studies, Mitchell, et al, (1981) compared septic tank effluent and aerobically treated effluent in terms of time until the soil column failed to infiltrate the effluent. They concluded strongly that pretreatment by aeration will definitely prolong the life of a septic tank filter field.

<u>Increase the infiltration rate.</u>

A variety of researchers have reported on the increased infiltration rate when the clogging zone is reduced or eliminated.

In column studies using loamy soil with no clogging mat, with even distribution and timed dosing, Duncan, Reneau and Hagedorn (1994) report that fecal coliforms were present in the 15 and 30 cm depths for septic tank effluent, at the 15 cm depths for constructed wetland effluent and not present at the 15 cm depth for recirculating sand filter effluent.

In studies using recirculating sand filter effluent, several researchers have found that highly pretreated effluent infiltration rates into soil will be much higher than those for septic tank effluent. Louden and Birnie (1991) report on a 3 year study on a 10 year old system. It received recirculating sand filter effluent at over 2 gpd/ft^2, where design loading rates for septic tank effluent would be 0.25 gpd/ft^2. They conclude that the use of recirculating sand filters to improve effluent quality prior to subsurface disposal in slowly permeable soils looks very promising. Other studies have produced similar results (Duncan, Reneau and Hagedorn 1994, Louden, Salthouse and Mokma 1998, Reneau, Hagedorn and Jantrania 2001).

Several review and analytical papers also describe increased infiltration rates associated with highly pretreated effluent and/or little or no clogging zone. (Otis 1984, Siegrist 1987a, Siegrist and Boyle 1987, Tyler and Converse 1994, Tyler, Converse and Keys 1995, Erickson and Tyler 2001). Several papers point out that loading rates of pretreated wastewater can be increased in sands more than in clayey soil (Tyler and Converse 1994, Tyler, Converse and Keys 1995).

Ability to remove pathogens

Some researchers have expressed concerns about increasing loading rates to infiltrative surfaces in the absence of a clogging zone. In a literature review, Yates (1987) has summarized research indicating that virus removal is inversely related to hydraulic loading rate. Converse and Tyler (1998a) report that increased infiltration rates to the infiltrative surface in the absence of a clogging zone will yield fecal coliforms deeper in the soil profile, therefore limiting the amount of downsizing possible. Although Higgens, Heufelder and Foss (1999) report finding a 2 log reduction in coliphage (virus that has bacteria as host cells) through a septic tank and gravity drainfield system without a clogging zone, they caution against coupling a reduction in vertical separation and reduction in drainfield size when applying highly pretreated effluent to the soil absorption component, since drainfield reduction translates to a higher hydraulic loading rate. They suggest that research is needed to show whether impedance to formation of a clogging mat appreciably affects the ability of the OSS to remove viruses. Van Cuyk and Siegrist (2001) discuss the need for fundamental understanding of the fate and transport of pathogens in SSAS before increasing loading rates to soil, based on high levels of pretreatment.

The concerns expressed in the above reports appear not to apply when pretreated effluent is applied at rates used for septic tank effluent and when even distribution and long intervals between dosings are used. In the column studies mentioned earlier, Duncan, Reneau and Hagedorn (1994) observed that fecal coliforms did not migrate as far as the 15 cm depth for recirculating sand filter (i.e. highly pretreated) effluent. The report by Converse and Tyler (1998a) of a study where increased loading rates yield fecal coliforms deeper into the soil profile suggests that concern for lack of clogging mat development comes when higher loading rates are used.

In addition, Anderson and Lewis (1992) have reported empirical findings that suggest that pathogen transport is very limited. They monitored groundwater down gradient from a subdivision and down gradient from individual on-site systems. These systems were conventional septic tanks and drainfields that had been in service long enough to have well-developed clogging zones. They found that human enteroviruses survive in septic tanks for up to 60 days and are discharged to the soil infiltration system but are not found in the ground water 10 feet down gradient. They conclude that groundwater transport of enterovirus down gradient from the OSS is not as likely as other water-carried constituents.

OTHER ISSUES AND CONCERNS WITH INCREASED LOADING RATES

In reviewing the literature for this topic, several issues and concerns were noted related to increased loading rates. Laak (1974) states that extensive pretreatment is best suited for very permeable and well-drained soils. Roats (1975) notes that soil clogging by extended aeration unit effluent is caused primarily by surface accumulation of suspended solids and that the clogging was more severe with extended aeration effluent than with septic tank effluent

Tyler and Converse (1989) say that it appears that pretreated effluent of high quality can be applied at higher rates than septic tank effluent. However, it is impossible to predict effluent loading rates for intermediate strengths of pretreated wastewater effluents. In these studies, the cut-off for highly pretreated effluent is <30 mg/l BOD.

Cost Information (if available & applicable):

Incentives, some of which are economic, for disposal component reductions are evident. Acceptance of higher hydraulic loading rates for higher quality effluents would provide sizing incentives such that improved pretreatment might be used. Additional treatment of septic tank effluent can be substituted for soil depth. Reductions in lot size may also be a possibility with increased loading rates.

Conclusions:

- Highly pretreated wastewater allows for discharge to subsurface infiltrative systems at increased hydraulic loading rates, compared to rates used for septic tank effluent, without stimulating soil clogging development. These results are dependent on equal distribution of the effluent.
- Pathogen transport in the absence of a clogging mat is limited when effluent is applied to the soil at rates used for septic tank effluent and with essentially timed dosing and equal distribution. This conclusion is based on several studies and on the fact that there are no studies that provide conflicting results.
- Researchers caution against increasing loading rates for highly treated effluent just because it can be done hydraulically. There is need to elucidate the fundamentals of pathogen transport in the absence of a clogging zone when highly pretreated effluent is applied at elevated hydraulic loading rates to assure public health and groundwater protection.
- Researchers also caution against coupling reductions to vertical separation and drainfield reductions based on highly pretreated effluent.
- Recommendations:
  - ⇒ Sizing reductions to absorption areas make sense hydraulically when highly treated wastewater is being applied to the infiltrative surface.
  - ⇒ Sizing reductions to the absorption area should be based on soil type to which the highly treated effluent is applied, as saturated hydraulic conductivity varies among the soil types.
  - ⇒ Sizing reductions based on highly pretreated effluent should incorporate in the system design features to assure unsaturated flows (equal distribution, doses spread evenly over time). Available research argues against application at saturated conductivity rates. Sizing reductions (and therefore increased hydraulic loading rates) to the absorption area should not be allowed if a reduction to the vertical separation is also being allowed based on the application of highly treated wastewater. Such loading rates, in the absence of a clogging zone will drive pathogens deeper into an already reduced vertical distance to ground water or restrictive layer.
  - ⇒ Be cautious about the allowance of reduced drainfields until the transport and fate of pathogens has been investigated.
  - ⇒ Science may support an increased hydraulic loading rate to some soils based on use of highly pretreated effluent without need for full-sized area set-asides for both primary and reserve areas. However, researchers caution that failure of the pretreatment component to deliver the high quality effluent will result in rapid clogging and hydraulic failure of the downsized soil absorption area. Therefore, for public health protection, two additional requirements must accompany reductions in absorption areas: monitoring and maintenance of the pretreatment component and full area set-asides for both the primary and secondary absorption areas.

References

Amerson, RS, Tyler, EJ, Converse, JC. 1991. Infiltration as Affected by Compaction, Fines and Contact Area of Gravel, in On-Site Wastewater Treatment: Proceedings of 6th National Symp. On Individual and Small Community Sewage Systems, American Society of Agricultural Engineers, St. Joseph, MI, December 1991.

The purpose of this study was to evaluate the effect of gravel on soil infiltration rates. Specifically, the objectives were to evaluate the effect of 1) soil compaction and smearing by falling gravel, 2) the fine earth material carried by gravel, and 3) the masking of the infiltrative surface caused by the contact area between the gravel and the soil. These experiments indicate that fines carried by gravel are a potentially greater problem in newly-constructed on-site wastewater treatment systems than either compaction by falling gravel or the contact area effect.

Anderson, DL, Lewis, AL. 1992. Human Enterovirus Monitoring at On-site Wastewater Disposal Systems, in Proceedings of 7th Northwest On-site Wastewater Treatment Short Course and Equipment Exhibition, University of Washington, Seattle, WA. September 1992.

This paper reports the results of groundwater monitoring down gradient of dense subdivisions served by on-site sewage systems. Parameters included human enteroviruses. This paper also reports investigations into the presence of enteroviruses in stool specimens, septic tank effluent, soil samples, and ground water samples at single family residences served by septic systems.
Conclusions:
1. Ground water transport of enterovirus down gradient from the OSSs in not as likely as other parameters.
2. Stool specimen examination indicated that enteroviral infections were relatively common and that viruses were shed into the septic system in high numbers.
3. Human enteroviruses are discharged in septic tank effluent and they can survive in the septic tank from 30-60 days.
4. Viruses do not appear to stay active for long periods in the soils below the OSSs. 5. Low numbers of viable virus can reach ground water 2-3 feet below an OSS, but they do not survive 10 feet down gradient.

Anderson, JL, Machmeier, RE, Hansel, MJ. 1982. Long-Term Acceptance Rates of Soils for Wastewater, in On-Site Sewage Treatment: Proceedings of 3rd National Symp. On Individual and Small Community Sewage Systems, American Society of Agricultural Engineers, St. Joseph, MI.

This paper is a literature review on the topic of long-term hydraulic acceptance rates for soil absorption systems. The authors list the following conclusions:
1. The preponderance of evidence supports the concept of long-term acceptance rates, rather than eventual failure.
2. Careful evaluation of soil and site factors, coupled with proper system design, construction, and maintenance will result in the ability to predict and maintain the acceptance rate on a long-term basis.

Converse, JC, Tyler, EJ. 1998b. Soil Dispersal of Highly Pretreated Effluent – Considerations for Incorporation into Code, in Proceedings of 7th Annual Conference and Exhibit, National On-site Wastewater Recycling Association, Northbrook, IL. October 1998. pp. 42-49.

The objectives of this paper are: 1) to summarize research relating to treatment performance of 3 types of pretreatment units, to summarize research related to soil dispersal of highly pretreated effluent, and 2) to discuss how these results might be interpreted and applied.

Field data collected from monitoring 20 single-pass sand filters, 21 aerobic units and 10 other aerobic units were evaluated with field data collected from beneath 39 modified mounds and at-grade units receiving highly pretreated effluent from aerobic units and sand filters to estimate separation distances from the infiltrative surface and seasonal saturation and bedrock.

Converse, JC, Tyler, EJ. 1998a. Soil Treatment of Aerobically Treated Domestic Wastewater with Emphasis on Modified Mounds, in On-Site Wastewater Treatment: Proceedings of 8th National Symp. On Individual and Small Community Sewage Systems, American Society of Agricultural Engineers, St. Joseph, MI, March 1998.

39 soil absorption units receiving aerobic unit or sand filter effluent were evaluated for a reduction in separation distance and downsizing. Based on median values, fecal coliform counts were not detected at distances greater than 30 cm in soils receiving effluent with mean fecal coliform counts <1000 mpn/100ml. System type (Modified mounds, at-grade), full or half-sized, and soil type did not affect the results. However, increased loading rates and elevated fecal coliform counts will yield fecal coliforms deeper in the soil profile, thereby limiting the amount of downsizing possible. Other portions of the study suggest that there is a limit to the mass loading rate (combination of wastewater strength and loading rate) to the soil for final polishing the effluent.

Daniel, TC, Bouma, J. 1974. Column Studies of Soil Clogging in Slowly Permeable soils as a Function of Effluent Quality, J Env. Quality 3(4):321-327.

Undisturbed 2 ft long soil cores of a very slowly permeable silt loam were subjected to constant ponding for 120 days. Liquid dose to the cores were STE, extended aeration effluent, and distilled water. Although column influents differed markedly, the effluents had consistently low levels of contaminants. The most severe barriers to infiltration were in columns flooded with extended aeration effluent, followed closely by STE. No barriers developed in columns ponded with water. This study points to the significant role of suspended solids in soil clogging.

Duncan, CS, Reneau, RB, Hagedorn, C. 1994. Impact of Effluent Quality and Soil Depth on Renovation of Domestic Wastewater, in On-Site Wastewater Treatment: Proceedings of 7th National Symp. On Individual and Small Community Sewage Systems, American Society of Agricultural Engineers, St. Joseph, MI, December 1994.

20 cm diameter soil columns were used in this study. They received effluent from either septic tank, constructed wetland or recirculating sand filter. Effluent was dosed 6 times a day at the rate of 2.6 gpd. Pretreatment with constructed wetland and recirculating sand filter resulted in 30% and 70% higher infiltration rates. Fecal coliform were present in the 15 and 30 cm depths for STE, at the 15 cm depth for constructed wetland effluent, and not even at the 15 cm depth for the recirculating sand filter effluent. Results from this study indicate that additional treatment of septic tank effluent can be substituted for soil depth.

Erickson, J, Tyler, EJ. 2001. A Model for Soil Oxygen Delivery to Wastewater Infiltration Surfaces, in On-Site Wastewater Treatment: Proceedings of 9th National Symp. On Individual and Small Community Sewage Systems, American Society of Agricultural Engineers, St. Joseph, MI, March 2001.

Soil could accept on-site wastewater at rates 2-3 orders of magnitude higher than the current design loading rates if a clogging mat at the wastewater infiltration surface was limited or not present. The clogging mat controls the system design, loading rate and life. Maintaining aerobic conditions at the infiltrative surface could substantially reduce or eliminate clogging. To maximize delivery of oxygen, soil components should be shallow, narrow and have separated infiltration areas. Design of the wastewater infiltration surfaces should be based on both oxygen transport and hydraulics. In many cases, oxygen transport will be limiting and therefore the basis for design. In order to increase the oxygen flux to the infiltrative surface, the design must be long, thin, and located close to the oxygen source.

Hargett, DL, Tyler, EJ, Siegrist, RL. 1982. Soil; Infiltration Capacity as Affected by Septic Tank Effluent Application Strategies, in On-Site Sewage Treatment: Proceedings of 3rd National Symp. On Individual and Small Community Sewage Systems, American Society of Agricultural Engineers, St. Joseph, MI.

This paper reports the results of a 21 month study that examined the rate and frequency of application

under a controlled, replicated loading regime, yet in natural undisturbed soil conditions. Conclusions are:
1. Loss of infiltrative capacity is related to the amount and frequency of wastewater applied over time.
2. The initial loss in system permeability is very rapid regardless of application rate or method.
3. Loading rates higher than appropriate for soil conditions cause the most rapid and continuous long-term declines in infiltrative capacity.
4. Conventional application, even at conservative rates, is likely to result in some degree of ponding.
5. Dosing results in higher infiltration rates as long as the application rate does not induce persistent ponding.
6. Dosing has little, if any, long-term advantage over conventional application for high loading rates.

Harpkin, JM, Jawson, MD. 1976. Clogging of Soil by Septic Tank Effluent and Its Oxidative Reversal, Proceedings of NW On-site Wastewater Disposal Short Course, Univ. of Washington, Seattle, WA, pp.53-61.

Annotation: This study used sand columns dosed with STE to describe the formation of clogging mats and the use of Hydrogen peroxide to clear the clogs.

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

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

Jenssen, PD, Siegrist, RL. 1990. Technology Assessment of Wastewater Treatment by Soil Infiltration Systems, Water Science Technology 22(3/4):83-92.

This is a review paper, and reports the following conclusions, especially as applied to large systems:
1. Present design criteria for large subsurface wastewater treatment systems are approximate and not always well-founded.
2. Poor siting is a main cause of early failure. For large subsurface systems, large-scale infiltration tests and tracer studies should be considered in siting procedures.
3. The hydraulic loading rate should be based on soil type and wastewater quality. Better pretreatment yields larger allowable loading rates.
4. In general, trench designs are preferred over beds.
5. A stepwise extension of the system is recommended, as the need arises. This approach will optimize the size and increase the overall cost-effectiveness.
6. Purification performance of subsurface wastewater infiltration systems is generally good. Estimates of purification on the basis of grain size, loading rate and soil depth can be given.

Keys, JR, Tyler, EJ, Converse, JC. 1998. Predicting Life for Wastewater Absorption Systems, in On-Site Wastewater Treatment: Proceedings of 8th National Symp. On Individual and Small Community Sewage Systems, American Society of Agricultural Engineers, St. Joseph, MI, March 1998.

This paper uses a mass-balance model to predict absorption system behavior and life span. It concludes:
An absorption system on sand soil loaded at .39 GPD has a predicted life of 11 years, and loaded at 1

GPD has a predicted life of 7 years.
Sidewall is very important part of transmitting effluent to the soil matrix. The clogged basal and sidewall areas need to accept the applied wastewater or at some point the trench will fill and the system will fail.

Kommalapati, RR, Noman, A. 1999. A Literature Review on Effects of Long-Term Effluent Infiltration Rates At On-site Sewage Disposal Systems, Paper submitted to the Texas On-site Wastewater Treatment Research Council, Austin, TX. October 1999.

This paper is a literature review. The conclusions stated in the article are:
1. There are two basic types of OSS failures: failure to treat, and failure to accept the hydraulic load.
2. Failure in the 1st 5 years of system life is typically due to hydraulic overload and failures after about 15 years are due to root clogging or factors such as improper or inadequate site and soils evaluation, improper system location, improper construction practices and lack of maintenance.
3. The main reason for failure is typically believed to be clogging mat development.
4. There are two concepts regarding long-term infiltration in the literature: progressive or creeping failure, and an equilibrium between growth and decomposition of the clogging mat that can be sustained with the appropriate loading rate.
5. The preponderance of evidence points to a long-tern acceptance rate.
6. The factors that affect the long-term acceptance rate are loading rate, clogging, soil evaluation, location, and construction practices.
7. Not yet possible to compile a set of rational design criteria for a failure-proof OSS.
8. Careful evaluation of soil and site factors, coupled with proper system design, construction and maintenance will result in the ability to predict and maintain the acceptance rate on a long-term basis.
9. Reducing the organic strength with pretreatment reduces soil pore plugging and has the potential for higher long-term infiltration or loading rates.
10. Wastewater quality and purification requirements should be considered with soil texture in designing the long-term acceptance rate.
11. Passing enforceable regulations including using the services of a certified professional for installation and maintenance increases the age at failure by 10 years.

Kristiansen, R. 1981. Sand Filter Trenches for Purification of Septic Tank Effluent: I. The Clogging Mechanism and Soil Physical Environment, J. Env. Qual., 10(3): 353-357.

Three sand filters received septic tank effluent at different loading rates using gravity feed. Rate and degree of ponding were observed. Aerobic conditions beneath the clogged zone are measured. Also, crust resistances, C/N ratios, and percentage of soil pore volume occupied by bacterial cells are reported.

Knopf, FW, Healy, KA, Laak, R. 1975. Soil Clogging in Subsurface Absorption Systems for Liquid Domestic Wastes, Progress in Water Technology (Pergamon Press, Gr. Britain), 7(3/4):767-774.

These authors reason that there must be an effluent application rate at which growth and die-off in the biomass of the clogging mat are in equilibrium with the amounts of nutrients being provided by the liquid. This research was to determine the key parameters of operation and develop the design criteria for the construction of systems which would function at this equilibrium point and thereby last indefinitely. They make the following conclusions:
1. Equal distribution of the incoming liquid over the infiltration surface in not mandatory, as long as all the surfaces can become effective as needed, i.e. they are all interconnected.
2. Timed dosing of the effluent has no benefit.
3. Increasing the hydraulic gradient does increase the infiltration rate, but not to the degree predicted by Darcy’s Law.
4. Continuous ponding leading to anaerobic conditions is not detrimental to the system’s operation.
5. Infiltrative surfaces are never “irretrievably” clogged.

Kropf, PW, Laak, R, Healy, KA. 1977. Equilibrium Operation of Subsurface Absorption Systems, J. Water Pollution Control Federation, pp 2007-2016.

These authors report findings from controlled column studies. Their conclusions are:
1. Intermittent dosing does not result in a higher average infiltration rate than continuous inundation.
2. Infiltration surfaces were never “irretrievably” clogged.
3. Infiltration rate is related to the prevailing hydraulic gradient.
4. For periods of low gradient the system must provide sufficient storage capacity.
5. The infiltration rate through the fully developed slime layer is independent of the supporting soil matrix. Thus, even in coarse soils sufficient storage capacity must be built into the system.
6. Sidewall area up to the distribution pipe can be counted as an infiltrative surface.
7. Continuous inundation of an infiltration surface for 80 weeks in an anaerobic environment did not affect the long-term acceptance rate.
8. A value of 0.2 to 0.5 gpd/ft^2 is suggested as long-term infiltration rate for all the wetted surfaces.

Laak, R. 1974. Influence of Pretreatment on Soil Clogging, Proceedings of 1st National Conference on Individual On-site Wastewater Systems, National Sanitation Foundation, Ann Arbor, MI. September 1974. pp. 109-116.

The author makes the following conclusions based on the research reported in this paper:
1. Removal of BOD and TSS from domestic sewage reduces soil clogging material and permits smaller seepage bed installations where soil hydraulic conductivity is not significant. A mature soil clogging mat shows continual changes in permeability and is desirable for treatment. The clogging mat will not clog to ultimate failure, but reaches a long-term equilibrium rate.
2. Black water or toilet wastes contribute 90% of the nitrogen, 50% of the phosphates and the majority of suspended solids in household sewage.
3. Extensive pretreatment is best suited for very permeable and well-drained soils.

Laak, R. 1976. Pollutant Loads from Plumbing Fixtures and Pretreatment to Control Soil Clogging, J. Environmental Health 39(1):48-50.

This article reports the relative contributions of pollutants from the various household fixtures. Also reported are the idea of soil clogging as a surface phenomenon, clogging process is not irreversible, the major factors in clogging are BOD and TSS, and pretreatment can be used to manage and reduce the clogging mat.

Laak, R. 1970. Influence of Domestic Wastewater Pretreatment on Soil Clogging, J. Water Pollution Control Federation, 42(8): Part I, pp.1495-1500.

This author concludes:
1. Increasing the pretreatment of domestic wastewater prior to soil application increases the service time of the soil surface.
2. Soil clogging failure loads should also be expressed in terms of TSS and BOD of the liquid. It seems that the service time of the soil surfaces is directly related to the sum of total SS and the BOD.
3. With further studies it should be possible to calculate the service time and removals of TSS and BOD for a variety of soils.

Louden TL. 1992. Performance of Trenches Receiving Sand Filter Effluent in Slowly Permeable Soils, in Proceedings of 7th Northwest On-site Wastewater Treatment Short Course and Equipment Exhibition, University of Washington, Seattle, WA. September 1992. pp. 164-182.

This paper reports the field experiences with two soil absorption systems receiving effluent from recirculating sand filters. Soil absorption performance data are presented.
1. For 3 years, the 10 year old system receiving RSF effluent has been taking the liquid at over 2 gpd/ft^2 where design loading rate for septic tank effluent would be .25 gpd/ft^2.
2. The use of a RSF to improve effluent quality prior to subsurface disposal in slowly permeable soils looks very promising.

Louden, TL, Birnie, GL. 1991. Performance of Trenches Receiving Sand Filter Effluent in Slowly Permeable Soils, in On-Site Wastewater Treatment: Proceedings of 6th National Symp. On Individual and Small Community Sewage Systems, American Society of Agricultural Engineers, St. Joseph, MI, December 1991. pp. 313-323.

This paper reports the field experiences with two soil absorption systems receiving effluent from recirculating sand filters. Soil absorption performance data are presented.
1. For 3 years, the 10 year old system receiving RSF effluent has been taking the liquid at over 2 gpd/ft^2 where design loading rate for septic tank effluent would be .25 gpd/ft^2.
2. The use of a RSF to improve effluent quality prior to subsurface disposal in slowly permeable soils looks very promising.

Louden, TL, Mokma, DL. 1999. Trench Infiltration as Influenced by Soil Type, Depth, Application Method and Effluent Quality, in Proceedings of 10th Northwest On-site Wastewater Treatment Short Course and Equipment Exhibition, University of Washington, Seattle, WA. September 1999. pp. 341-352.

This article is an essay based on the authors' knowledge and experience. The discussion illustrates the many advantages of shallow systems, pressure dosing and improved effluent quality. Shallow systems place the wastewater in the most biologically active part of the soil, which is usually also the most permeable. Shallow placement will have more sorptive sites for contaminant removal and a high concentration of soil organisms as antagonists to pathogens. Good aeration will contribute to die-off of pathogens, nitrification, and degradation of organic components of the wastewater.

Pressure distribution combined with shallow systems can reduce the formation and severity of the clogging mat.

Pretreatment with sand filters or other processes that result in highly treated wastewater reduce or eliminate formation of the clogging mat. Soils retain their natural infiltration rate characteristics and can be loaded at a higher hydraulic loading rate so long as the soil below will be able to transmit the water away from the zone of application.

Louden, TL, Salthouse, GS, Mokma, DL. 1998. Wastewater Quality and Trench System Design Effects on Soil Acceptance Rates, in On-Site Wastewater Treatment: Proceedings of 8th National Symp. On Individual and Small Community Sewage Systems, American Society of Agricultural Engineers, St. Joseph, MI, March 1998. pp. 186-194.

Sand filter effluent infiltrated into the bottom of standard gravel trenches 22-24 inches deep at rates 7-12 times greater than septic tank effluent.

Magdoff, FR, Bouma, J. 1975. The Development of soil Clogging in Sands Leached with Septic Tank Effluent, in Proceedings of National Home Sewage Disposal Symposium, American Society of Agricultural Engineers, St. Joseph, MI, 1974. pp. 37-47.

This paper describes soil clogging with septic tank effluent in detail and compares some measurements with the same measurements on 4 field installations.

McGauhey, PH, Winneberger, JHT. 1964. Causes and Prevention of Failure of Septic Tank Percolation Systems, FHA No. 533, Federal Housing Administration, Washington DC. 66 p.

McGauhey, PH, Winneberger, JH. 1964. Studies of the Failure of Septic Tank Percolation Systems, J. of Water Pollution Control Federation, 36(5):593-606.

This early paper reports observations and conclusions related to the loss of infiltrative capacity of soil receiving septic tank effluent. They conclude:
Necessary aerobic conditions in a percolation system cannot be maintained when a soil is continuously inundated.

For a ST-DF system to function satisfactorily, several basic conditions must be maintained: Soil must be sufficiently permeable to transport water at some acceptable percolation rate. It must be free of impermeable lenses. It must be free of swelling colloids. The groundwater must lie at sufficient depth below the infiltrative surface that liquid will drain from the site of application. Percolation tests are a poor design tool.
Much of the loss of infiltrative capacity is directly traceable to the organic fractions of sewage, which lead to clogging by suspended solids, bacterial growth and ferrous sulfide precipitation.
Intermittent dosing and draining of the soil system are necessary to the maintenance of optimum infiltration rates.

Mitchell, DT, Rutledge, EM, Mote, CR, Scott, HD. 1981. Soil Column Comparison of Aerobically Pretreated Wastewater to Septic Tank Effluent, in On-Site Wastewater Treatment: Proceedings of 3rd National Symp. On Individual and Small Community Sewage Systems, American Society of Agricultural Engineers, St. Joseph, MI, December 1981. pp. 266-272.

This study compares the clogging effects of aerobically treated effluent with septic tank effluent. They report:
1. In general, pretreatment by aeration will definitely prolong the life of a septic tank filter field.
2. Depending on hydraulic loading, this prolongation may be significant.
3. All filter fields, whether they receive pretreated wastewater or untreated septic tank effluent, will fail with prolonged hydraulic overloading.
4. Recovery by resting is unlikely in soil leach fields receiving pretreated wastewater.

Otis, RJ. 1984. Soil Clogging: Mechanisms and Control, in On-Site Wastewater Treatment: Proceedings of 4th National Symp. On Individual and Small Community Sewage Systems, American Society of Agricultural Engineers, St. Joseph, MI, December 1984. pp. 238-250.

This paper is a literature review of studies which investigated soil clogging as a result of wastewater infiltration, and explores methods to control the clogging. Specific observations and recommendations are:
1. Control of soil clogging requires good site selection and design.
2. Narrow trenches are preferred to beds.
3. Small reductions in the resistance of the clogged zone will have a profound effect on the rate of infiltration.
4. Intermittent dosing and resting will prolong the life of the infiltration system.

Otis, RJ. 2001. Boundary Design: A Strategy for Subsurface Wastewater Infiltration System Design and Rehabilitation, in On-Site Wastewater Treatment: Proceedings of 9th National Symp. On Individual and Small Community Sewage Systems, American Society of Agricultural Engineers, St. Joseph, MI, March 2001. pp. 245-260.

This paper presents a rational strategy for system design and diagnosing system failures.

Pell, M, Ljunggren, H. 1985. Reduction of Organic Matter with Focus on the Clogging Phenomenon, Proceedings of the International Conference on New Technology of Wastewater Treatment and Sewerage in Rural and Suburb Areas, Hanassari, Finland. pp. 311-327.

This paper reports the results of a study to investigate some of the factors of importance in the soil clogging process. They also found that the bacterial populations did not need to adapt to changing quality of the incoming effluent.

Reneau, RB, Hagedorn, C, Jantrania, AR. 2001. Performance Evaluation of Two Pre-Engineered On-site Treatment and Effluent Dispersal Technologies, in On-Site Wastewater Treatment: Proceedings of 9th National Symp. On Individual and Small Community Sewage Systems, American Society of Agricultural Engineers, St. Joseph, MI, March 2001. pp. 271-280.

This study tests the capacity of an ATU and a recirculating media filter (RMF) to remove the various constituents of sewage. It also shows that effluent from a RMF can be applied to a soil infiltration surface at rates 2-5 times higher than septic tank effluent rates.

Roats, GG. 1975. Effect of Domestic Wastewater Pretreatment on Soil Clogging under Aerobic and Anaerobic Conditions, Master's Thesis, School of Civil Engineering, University of Washington, 76 pages.

This document is a master's thesis. Roats combined a literature search with some soil column studies to reach his conclusions.
1. Clogging of Alderwood gravelly sandy loam was more severe under application of extended aeration unit effluent than under application of septic tank effluent.
2. Soil clogging by extended aeration unit effluent appeared to be caused primarily by surface accumulation of suspended solids, with microbial growth playing a minor role, if any.
3. Soil clogging by septic tank effluent was caused by a combination of suspended solids filtration and microbial growth, but it was not clear which factor was more important.

Siegrist, RL. 1987a. Soil Clogging During Subsurface Wastewater Infiltration as Affected by Effluent Composition and Loading Rate, J. Environmental Quality, 16(2):181-187. April-June 1987.

This study used pilot-scale infiltration cells installed in structured silty clay loam. These cells were loaded over a 70 month period with either domestic septic tank effluent, graywater septic tank effluent or tap water. The liquids were applied in an average of 5.2 doses per day to yield daily loading rates of 0.32, 0.63 and 1.27 gpd. The researcher made the following observations:
1. Soil clogging was negligible in all tap water treatments and in the graywater units receiving 0.32 and 0.63 gpd.
2. In Graywater units receiving 1.27 gpd and all domestic septic tank effluent units severe soil clogging led to continuous ponding of the soil infiltrative surface.
3. Soil clogging development is highly correlated with the cumulative mass density loadings of total biochemical oxygen demand and suspended solids.
4. Clogged infiltrative surface zones exhibited significant accumulations of organic materials at the infiltrative surface and within the first few millimeters of the soil matrix.
5. Higher quality wastewater effluents can be discharged to subsurface infiltration systems at hydraulic loading rates in excess of those utilized for domestic septic tank effluent without stimulating soil clogging development.

Siegrist, RL. 1987b. Hydraulic Loading Rates for Soil Absorption Systems Based on Wastewater Quality, in On-Site Wastewater Treatment: Proceedings of 5th National Symp. On Individual and Small Community Sewage Systems, American Society of Agricultural Engineers, St. Joseph, MI, December 1987. pp. 232-241.

This paper examines wastewater effluent quality as a factor in soil absorption system design and discusses an alternative approach to conventional design practice. He concludes:
1. Wastewater quality and hydraulic loading rate are primary factors in soil clogging development.
2. Mass loadings of BOD and TSS appear to be key determinants of soil clogging development and system design should account for this.
3. Acceptance of higher allowable hydraulic loading rates for higher quality effluents would provide sizing incentives such that improved pretreatment processes might be used.
4. Lower loading rates for lower quality effluents would help mitigate harmful an costly performance malfunctions.

Siegrist, RL, Boyle, WC. 1987. Wastewater Induced Soil Clogging Development, Journal of Environmental Engineering, ASCE 113(3):550-566.

Soil clogging development in intermittently loaded subsurface wastewater infiltration systems is a long-term process.
1. Soil clogging development is highly correlated with the cumulative mass density loadings of total BOD and TSS.
2. Proper design of these systems should include consideration of wastewater effluent composition as well as hydraulic loading rate.
3. Soil clogging can be delayed or altogether mitigated by reducing the applied mass loading rates of BOD and TSS either through lower hydraulic loading rates or by reduced effluent concentrations.
4. Reduced concentration of BOD and TSS can facilitate the use of higher hydraulic loading rates without accelerating soil clogging.

Simon, JJ, Reneau, RB. 1987. Recommended Septic Tank Effluent Loading Rates for Fine-Textured, Structured Soils with Flow Restrictions, in On-Site Wastewater Treatment: Proceedings of 5th National Symp. On Individual and Small Community Sewage Systems, American Society of Agricultural Engineers, St. Joseph, MI, December 1987. pp. 394 - 411.

Conclusions:
1. Texture should not be the sole criteria for determining the design loading rate for soil absorption systems. A major emphasis should be placed on including soil structure as a key evaluation tool.
2. Presence of large amounts of coarse fragments or intermittent beds of weathered rock should be the basis for using reduced loading rates in soils that are otherwise well structured.
3. Fine textured soils which appear to be well drained should provide adequate treatment of effluent, and SAS longevity should occur, provided that loading rates are partially determined relative to soil structure.
4. It is imperative that uniform distribution of effluent is also a design factor or else localized overloading may eventually result in system failure.

Sobsey, MD, Dean, CH, Knuckles, ME, Wagner, RA. 1980. Interactions and Survival of Enteric Viruses in Soil Materials, Applied and Environmental Microbiology, 40(1):92-101.

This article reports from a laboratory study on the adsoption, retention and elution of two different viruses in several soil and suspended soil media and over a range of pH and cation concentrations. The results of the study indicate that it may be possible to distinguish soil material into several classes with respect to virus adsorption and retention. These classes involve textural, mineralogical and chemical characteristics. More studies are needed to fully characterize viral behavior with respect to soil features and chemistry. One part of the investigation (viral survival in soil suspensions) suggest that viruses in saturated soils may remain infectious for considerable periods of time, even at moderate soil temperatures (20^{o} C) where soil would be microbially active.

Stewart, LW, Carlile, BL, Cassel, DK. 1979. An Evaluation of Alternative Simulated Treatments of Septic Tank Effluent, J. Env. Quality, 8(3): 397-403.

This column study used two types of unsaturated material (loamy sand topsoil and a mixture of loamy sand topsoil and sand) over two types of saturated material (histic epipedon-sand mixture and gravel), such that all four combinations were tested. They concluded that an unsaturated zone of material with 92% sand-sized particles can be used in an artificially created sewage treatment and disposal system, dosed at 0.8 gpd/ft^2 and still take advantage of the aeration and hydraulic properties of sand without sacrificing effective treatment of septic tank effluent. They found no penetration of fecal coliforms beyond 30cm (12”), and found 83-100% conversion of total nitrogen to NO_3 at 95 cm (37”).

Tyler, EJ. 2001. Hydraulic Wastewater Loading Rates to Soil, in On-Site Wastewater Treatment: Proceedings of 9th National Symp. On Individual and Small Community Sewage Systems, American Society of Agricultural Engineers, St. Joseph, MI, March 2001. pp. 80 - 86.

This paper has little to do with soil clogging and loading rates. Its main topic is the movement of water already infiltrated into the soil.
1. The rate of transmission of the infiltrated water through the soil away from the infiltrative 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.
2. A table, based on logic and experience, is presented to estimate the design infiltration loading and hydraulic linear loading rates for on-site sewage systems.

Tyler, EJ, Converse, JC. 1989. Hydraulic Loading Based Upon Wastewater Effluent Quality, in Proceedings of 6th Northwest On-site Wastewater Treatment Short Course and Equipment Exhibition, University of Washington, Seattle, WA September 1989. pp. 163 – 172.

This paper provides a conceptual analysis that long term acceptance rates are influenced by the wastewater effluent quality. It appears that pretreated effluent of high quality can be applied at higher rates than septic tank effluents. However, it is impossible to predict effluent loading rates for intermediate strengths of pretreated wastewater effluents.

Tyler, EJ, Converse, JC. 1994. Soil Acceptance of On-site Wastewater as Affected by Soil Morphology and Wastewater Quality, , in On-Site Wastewater Treatment: Proceedings of 7th National Symp. On Individual and Small Community Sewage Systems, American Society of Agricultural Engineers, St. Joseph, MI, December 1994. pp. 185 – 194.

Maintaining the wastewater infiltrative surface in the soil is dependent on never exceeding the design hydraulic of BOD and SS loading rate. Design and maintenance procedures must assure that only the highly pretreated wastewaters reach the soil. Conclusions of the authors:
1. Reducing organic materials with wastewater pretreatment systems reduces soil pore plugging and has the potential for higher long-term infiltration or loading rates.
2. Loading rates of pretreated wastewater in sands can be increased more than in clayey soil.
3. Rates for highly pretreated wastewaters might be 2-16 times greater than rates recommended for septic tank effluent.
4. The higher the loading rate the more attention needs to be paid to construction practices and materials, and the addition of hydrolysable cations.
5. Higher loading rates reduce the wastewater retention time and thus the wastewater treatment in the soil.
6. In the event of a pretreatment system failure to deliver highly pretreated effluent to the soil, it is likely that a rapid hydraulic failure of the soil system will occur.
7. A table is presented with a set of possible loading rates to consider for highly pretreated wastewaters. The greatest reduction in infiltration area for using highly pretreated effluent is for the coarser sands and the least is for the more slowly permeable soils.

Tyler, EJ, Converse, JC, Keys, JR. 1995. Soil Acceptance of Wastewater Affected by Wastewater Quality, in Proceedings of 8th Northwest On-site Wastewater Treatment Short Course and Equipment Exhibition, University of Washington, Seattle, WA. September 1995. pp. 96 – 109.

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

This study reveals a dynamic, interactive behavior for hydraulic and purification processes that are similar for systems using gravel and gravelless infiltrative surfaces and 2 feet or 3 feet of unsaturated flow.

Van Cuyk, S, Siegrist, RL. 2001. Pathogen Fate in Wastewater Soil Absorption Systems as Affected by Effluent Quality and Soil Clogging Genesis, in On-Site Wastewater Treatment: Proceedings of 9th National Symp. On Individual and Small Community Sewage Systems, American Society of Agricultural Engineers, St. Joseph, MI, March 2001. pp. 125 – 136.

This paper discusses the need for fundamental understanding of the fate and transport of pathogens in SSAS before increasing loading rates to soil based on high levels of pretreatment. Whereas this practice may be achievable hydraulically, but the relationship between hydraulic loading rate and quality of applied effluent and their effect on pathogen purification performance is required to utilize soil-aquifer systems effectively while preventing ground water contamination.

Wang, DS, Gerba, CP, Lance, JC. 1981. Effect of Soil Permeability on Virus Removal Through Soil Columns, Journal of Applied Environmental Microbiology. 42:83-88.

Wert, S, Paeth, RC. 1985. Performance of Disposal Trenches Charged with Recirculating Sand Filter Effluent, in Proceedings of 5th Northwest On-site Wastewater Treatment Short Course and Equipment Exhibition, University of Washington, Seattle, WA. September 1985. pp. 166 – 181.

This study inspected and analyzed samples taken from absorption trenches from two systems which received effluent from recirculating sand filters serving single-family residences. The systems had been in service for 3 years, were located in well-structured silty clay loams, and the trenches were arranged in serial distribution. In both cases, only the first trench was being used, and during the winter months ponded with groundwater with up to 20 inches of water without surface breakout. Soils were saturated immediately adjacent to the downslope side of the trenches. Sampling wells downslope showed that fecal coliform densities were reduced by more than 99% within 20 feet downslope. Acceptance rates were 2.8 gal/ft^2 in one system and 1.89 gal/ft^2 in the second system.

Yates, MV. 1987. Septic Tank Siting to Minimize the Contamination of Groundwater by Microorganisms, U.S. EPA, Office of Water Protection, EPA/440/6-87-007.

This manuscript describes a rating system to be used as a tool in siting on-site sewage systems. Included is a literature review to determine what factors are important in influencing the survival and migration of microorganisms in the subsurface environment. Factors evaluated were: depth to water, net recharge, hydraulic conductivity of the soil, temperature, soil texture, aquifer medium, application rate, distance to a well.

She writes: “The rate at which the effluent is applied to the soil is important in that the lower the application rate, the longer the time available for adsorption and retention of the microorganisms by soil particles. The results of a study by Wang et al. (1981) led the authors to suggest that the rate at which the water is applied to the soil may be the most important factor in predicting the potential for virus movement into the ground water”.