RULE DEVELOPMENT COMMITTEE ISSUE RESEARCH REPORT DRAFT

- ORGANIC LOADING RATES –

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Topic & Issues:

Organic Loading Rates

Current design standards only address hydraulic loading. The purpose of this review is to examine existing literature to answer the following questions:

- Does organic strength affect loading rates?
- Should organic loading be a consideration in designing infiltrative surfaces?
- By what approach should organic loading be addressed in system design?
- Based upon this literature review, do we have enough information to incorporate this concept into rule?

Summary:

BACKGROUND. Research indicates that, organic loading rates can be used to design the infiltrative surface for high strength septic tank effluent (STE). LITERATURE. Documents included in this review include: 5 journal articles, 20 conference proceedings papers, 11 government reports or guidance documents, 1 Master's Study Report, and one textbook. FINDINGS. This review demonstrated that information is available on organic loading and its relationship with the infiltration surface. This information could be used to design infiltration surfaces as an alternative to, or in combination with additional pretreatment. CONCLUSIONS. Dependent on the results of further research or field testing, the use of organic loading rates may be a viable option for drainfield design.

KEYWORDS: *(organic loading rates, BOD, COD, infiltration rate, infiltrative surface, subsurface disposal)*

Introduction:

Organic loading rate is defined as the application of soluble and particulate organic matter. It is typically expressed on an area basis as pounds of BOD_5 per unit area per unit time, such as pounds of BOD_5 per square foot per day ($lb/ft^2/day$). The concept of using organic loading rates to size an infiltration surface is based on the currently allowable hydraulic loading rates and typical organic concentrations of residential septic tank effluent (STE). Based on a typical waste strength of 150 mg/L (Siegrist, et al, 1984 and 1985; Siegrist, 1987; Hargett, et al, 1982), residential STE generates approximately 0.45 lbs of BOD_5 per day. In Washington State, hydraulic loading rates allow this effluent to be applied between 0.2 and 1.2 gpd/ft^2, which translates to an application of BOD_5 at a rate between 0.25 and 1.5 lbs. BOD_5 per 1,000 ft^2 per day. The calculations section of this review demonstrates that an infiltrative surface can be designed proportionally larger (or smaller) that will receive STE at the same, or lower, loading of BOD_5 and TSS per unit area that is currently allowed for residential-strength STE. In general, for higher strength STE, the infiltration surface will be proportionally larger; and for lower strengths, it will be proportionally smaller.

The potential to use organic loading rates to determine infiltrative area is currently available in WA. State for Large On-Site Systems (LOSS), but a methodology for use is not clearly identified and approval is on a case-by-case basis and limited to waste strength with $BOD_5 < 500$ mg/L.

The purpose of this review is to synthesize the literature available on the topic of organic loading rates so that the Technical Review Committee can make appropriate recommendations about loading rate requirements to the Rule Development Committee. More than 38 publications, which include peer reviewed journal articles, conference proceedings, government reports, and one Master's Study Report were collected and reviewed. Even through the majority of the publications are conference proceedings, which are typically not peer reviewed, they provided useful information regarding studies of the behavior of the clogging layer relative to organic loading and some investigations in the design of the infiltrative surface based on BOD content.

ORGANIC LOADING RATES

Organic loading rate is defined as the application of soluble and particulate organic matter. It is typically expressed on an area basis as pounds of BOD per unit area, such as lb $BOD_5/ft^2/day$ (Otis, 2001; Siegrist, 1987a). Control of organic loading can be accomplished by pretreatment to reduce the BOD and TSS concentrations or by increasing the size of the infiltration area to reduce the mass loading per unit area.

The traditional method of sizing an infiltration area is based on choosing appropriate hydraulic loading rates for site-specific soil characteristics. This technique fails to take into account changes in strength of the applied wastewater. "The design practice of household systems is often directly applied to commercial systems with little modification except for an adjustment of the design daily flow. Design and operation of commercial systems generally does not account for wastewater flow variations, organic loading, problem wastewater constituents or other factors commonly considered in engineering other non-soil absorption wastewater facilities." (Siegrist et al, 1984). However, mass loadings of wastewater constituents are typically used in the design of other wastewater facilities, such as surface land-treatment systems and mechanical treatment plants, to facilitate long-term operation. For those facilities, typical organic loading rates range between 0.2 and 5.0 lbs. BOD_5 / 1000 ft^2 per day (Crites & Tchobanoglous, 1998; Otis, 2001).

Several studies have shown that soil clogging is a function of the wastewater strength or concentration of BOD and TSS. Research has evaluated the impact on the clogging layer of increased hydraulic loading of highly pretreated STE and/ or of increased organic loading at typical hydraulic loading rates. For example, Laak studied the impact of increased infiltration rates of pretreated STE on the behavior of the clogging layer. He concluded that the concentration of BOD_5 and TSS were significant factors in the life of a drainfield. His research found that decreasing the sum of BOD_5 and TSS increased the infiltration rates in sands by a factor of

$$[(BOD5 + TSS) / 250]^{1/3}$$

He later proposed use of this formula to adjust the area of the infiltrative surface based on STE quality. Laak's formula is:

$$\text{Adjusted Area} = \text{Area}_{\text{(hydraulic loading)}} \times [\ (\text{BOD5} + \text{TSS}\ ) / 250\ ]^{1/3}$$

However, it should be noted that this formula was developed and studied for highly pretreated wastewater, and was not studied for the application high-strength STE to the infiltrative surface. It should also be noted that this factor did not apply in soils with low permeability (Laak, 1976, others).

Results of investigations by several researchers indicate that highly pretreated wastewater can be applied at significantly higher hydraulic rates than typical residential strength STE. (Erickson & Tyler, 2001; Hargett, Tyler & Siegrist, 1982; Laak, 1970; Otis, 1984; Otis, 2001; Siegrist, Anderson, & Converse, 1985; Siegrist & Boyle, 1987; Siegrist, 1987a; Siegrist, Tyler, & Jenssen, 2000; Tyler & Converse, 1989; Tyler, Converse, & Keys, 1995; and others.) (See the Hydraulic Loading Rates Issue Paper for more background.) Conversely, Siegrist (1987) concluded that more concentrated STE could be applied at correspondingly lower rates. In other words, the infiltration surface could be designed based on the organic mass loadings.

The Seagrist (et al, 1984) study, which focused on restaurant STE, showed that the wastewater constituent mass loadings are at least as important as hydraulic loading rates, and are critical in the design process. The organic loading rates measured in this study ranged from 8.8 to 99.8 lb BOD_5/acre/ day (0.202 to 2.29 lb BOD_5/1,000 ft^2/ day). Four of the systems that performed poorly were loaded with BOD at rates in excess of 40 lb BOD_5/acre/ day (0.918 lb BOD_5/1,000 ft^2/ day) in absorption beds. The average concentrations of BOD_5 were 2.7 times higher in restaurant STE than in typical residential STE and the TSS values were 2.8 times higher. This indicates that the BOD_5 and TSS mass loadings in 1.25 gpd/ft^2 of domestic STE were equal to those in approximately 0.45 gpd/ft^2 of restaurant STE. The results of this study suggested that the maximum organic loading for STE applied to a bed in sandy soil should be approximately 0.70 gpd/ft^2, 40 lb BOD_5/acre/day (0.918 lb BOD_5/1,000 ft^2/ day), and 15 lbs TSS/acre/day (0.344 lb BOD_5/1,000 ft^2/ day). Lower rates would be anticipated for beds in finer textured soils. The organic loading rates would be expected to be somewhat higher for long, narrow trenches in sandy soils.

According to Siegrist, the design of soil absorption systems should ideally integrate the composition and loading rate of applied wastewater with the properties of the soil system, including the natural soil properties and those induced by application of wastewater. His design approach would result in a strategy that would accomplish the hydraulic and treatment objectives and mitigate harmful and costly performance malfunctions. The design process would include the selection of hydraulic loading rates based on wastewater quality considerations in order to yield acceptable hydraulic performance (i.e. acceptable soil clogging development). This approach is based on the premise that in a given soil environment the mass loading of BOD and TSS are positively correlated with development of the clogging layer. Providing the hydraulic loading rates are such that the soil moisture contents don't approach saturation and cause anoxic soil conditions, clogging development will be roughly equivalent at equivalent mass loading rates. The specifics of this design process have not been rigorously evaluated to date; however, Siegrist states that field experience supports the concept.

A recent study by Matejcek, et al, at the University of Florida, Department of Civil & Coastal Engineering, investigated the properties and long-term acceptance rate (LTAR) of STE from restaurants. This study was conducted in phases from 1997 to 2001 for the Florida Department of Health. The study evaluated the behavior of various soils loaded with a range of concentrations of simulated 'high-strength' STE. This research concluded that the mass-loading rate should be included with soils properties and hydraulic loading rate in determining the size of a restaurant's drainfield. The major finding in this work is the identification of an upper limit for organic loading. The results suggested that the maximum organic loading rate lies between 1.5 and 2.4 lbs. BOD_5 per 1000 ft^2 per day. The recommended maximum loading rate for sands is 1.5 lbs. BOD_5 per 1000 ft^2 per day unless additional research is conducted to further clarify the upper limit. The Florida study is the only research found to date that specifically studied LTARs for high-strength STE.

The issue of dosing and waste strength was addressed by Ruskin (1999). This paper dealt specifically with subsurface drip systems, and with BOD_5 strength typical of residential STE (< 300 mg/l BOD_5). However, Ruskin suggested that the orifice discharge rate and orifice spacing are functions of waste strength. This paper suggests that both orifice spacing and discharge rate are inversely related to waste strength.

Shoemaker, et al (1987), discussed the issue of orifice plugging in pressure distribution systems for sand filters, and recommended minimum residual system pressures to avoid orifice clogging. However, the research did not address BOD_5 strengths studied.

The concept of using organic loading rates appears to be a very important element in sizing of infiltrative surfaces, and may be applicable to all STE. However, as several researchers have stated, the application of this concept has not been vigorously field-tested. As such, there are still some concerns, such as:

- Will the change in waste strength impact design parameters in the Pressure Distribution RS&G?
- Fats, oils, and greases must still be minimized in the effluent to the infiltrative surface.
- If the concentration of BOD_5 and TSS is highly variable, then some pretreatment may be required to control the waste strength.
- If pretreatment is not part of the process, there may be little or no control over the effluent quality. Some method of effluent quality monitoring may be necessary.

DESIGN CALCULATIONS

The actual or anticipated BOD_5 concentration can be factored in the calculation and an appropriate infiltration surface designed. That approach is demonstrated in the following calculations.

Organic Loading Calculation

Hydraulic Loading sizing:

Area (sq. ft.) = Design Flow (gpd)/ Hydraulic Loading Rate (gpd/sq ft)

Organic Loading calculation:

Organic Load (lbs BOD_5/day) =
BOD_5[1] (mg/L) x Design Daily Flow (gpd) x 8.34 x 10^{-6} (conversion from mg/L to lbs./gal.)

$$\text{Area (sq. ft.)} = \frac{BOD_5\ \text{(lbs./day)}}{\text{Organic Loading Rate (lbs. } BOD_5/\text{ ft}^2/\text{day)}}$$

Although residential STE has a range of BOD_5 values, it is typically assumed contain approximately 150 mg/L BOD_5. (Siegrist, et al, 1984 and 1985; Siegrist, 1987; Hargett, et al, 1982) In Washington State, a typical residential on-site system has a design flow of 360 gpd (3-bedroom home x 120 gpd/bedroom). Therefore, residential STE typically produces approximately 0.5 lbs. BOD_5 per day. (150 mg/l x 360 gpd x 8.34 x 10^{-6} = 0.45 lbs/day)

The following table presents the infiltrative surface required for various soils based on requirements in WAC 246-272. The table further provides the theoretical organic load in lbs. BOD_5/ ft^2 (and per 1000 ft^2) for domestic STE. From this allowable load, the infiltrative surface area required for the same organic loading rate could be calculated for higher (or lower) strength waste.

Residential Strength STE – Washington State			
Hydraulic Loading Rate[1] (gpd/ ft^2)	**Required Infiltrative Surface Area for Domestic STE for 360 gpd (ft^2)**	**Theoretical Organic Loading Rate[2] (lbs. BOD_5/ ft^2/day)**	**Theoretical Organic Loading Rate[2] (lbs. BOD_5/ 1000 ft^2/day)**
0.2	1800	.00025	0.25
0.45	800	.00056	0.56
0.6	600	.00075	0.75
0.8	450	.001	1.0
1.0	360	.0012	1.2
1.2	300	.0015	1.5

1. From WAC 246-272-11501, Table V
2. Based on typical residential STE (150 mg/L BOD_5). These values were obtained by using the Organic Loading Area formula, above. These values appear to be generally consistent with findings in the University of Florida (Matejcek) studies.

Therefore if the site conditions allow a hydraulic loading rate of 0.6 gpd/ft^2 and an organic loading rate of 0.83 lbs. BOD_5/ 1000 ft^2/day based on typical residential STE, then a drainfield could be sized for the same site but a different BOD_5 as follows:

Example:

Assume that the infiltration area must be designed for a restaurant with septic tank effluent having the following characteristics:

BOD_5 = 800 mg/L
Design flow = 600 gpd
Hydraulic loading rate = 0.6 gpd/sq ft

$$\textbf{Area}_{\text{(hydraulic loading)}} = 600 \text{ gpd} / 0.6 \text{ gpd/ sq ft} = \mathbf{1{,}000\ ft^2}$$

compared with

$$\text{Organic Load} = 800 \text{ mg/L} \times 600 \text{ gpd} \times 8.34\times10^{-6} = 4 \text{ lbs. } BOD_5\text{/ day}$$

At an allowable hydraulic load of 0.6 gpd/ ft^2, the allowable organic load is 0.75 lbs. BOD_5/ 1000 ft^2/ day Therefore, the required infiltrative area for this STE would be:

$$\textbf{Area}_{\text{(organic loading)}} = \frac{4 \text{ lbs. } BOD_5\text{/ day}}{0.75 \text{ lbs. } BOD_5\text{/ } 1000\ ft^2\text{/ day}} \quad \text{or} \quad \mathbf{5{,}333\ ft^2}$$

Washington State's Experience

Washington State currently allows Large On-Site Systems (LOSS) with moderately high strength STE an option in design of the infiltrative surface. (1) The first option is pretreatment of the STE to reduce the effluent strength until equivalent to residential strength or better. The pretreated effluent is then applied to the infiltrative surface at hydraulic loading rates per WAC 246-272-11501. This option is available to all systems. (2) The second option is available only to systems for which the BOD_5 is < 500 mg/L. That option allows a proportional reduction of the hydraulic loading rate so that the BOD_5 loading per unit area per unit time is constant. Option (2) currently requires case-by-case approval and is not explained clearly in the Standards. Smaller on-site systems (< 3,500 gpd) are not allowed option (2).

It was not feasible to gather data from on-site system files for this literature review. However, based on discussions with George Schlender and Lisa Brown, formerly of the Large On-Site Program (LOSS), very few systems have taken advantage of design option (2). (There may have been only 2 systems that designed a larger drainfield to accept the STE at residential strength organic loading.) The decision to allow this option only for systems with <500 mg/L BOD5 was based on recommendations from the LOSS committee at the time (early to mid-1980's), and generally related to practicality and economics. The size of the drainfields would become significantly more expensive above 500 mg/L. The exclusion of smaller systems from this option was based on experience at the time (same time period) that very few of the smaller systems monitored waste strength.

Other States' Experience

The State of Alabama allows the infiltrative surface to be designed based on BOD loading for non-residential facilities. The following table is used in the calculation:

Soil Texture Group	Organic Loading (lbs BOD / ft^2 per day)	Hydraulic Loading (gpd/ft^2)
Group 1 (Perc. 10 – 20)	.00100	1.5
Group 2 (Perc. 21 – 40)	.00080	1.0
Group 3 (Perc. 41 – 60)	.00061	0.65
Group 4 (Perc. 61 – 90)	.00030	.028

The infiltrative surface is then sized with the following formula:

$$\text{Area} = \textbf{larger of} \quad \frac{\text{Max. BOD Load (lbs BOD/ day)}}{\text{Organic Loading Rate (from the above Table)}} \quad \text{or} \quad \frac{\text{Design Flow (gpd)}}{\text{Hydraulic Loading Rate (from above table)}}$$

The State of Maine uses a factor very similar to the one proposed by Laak. In Maine, drainfields are sized based on the hydraulic loading rate and a factor determined by the sum of BOD_5 + TSS. The factor correlates fairly closely with Laak's. A table of the adjustment factors follows:

$$\text{Area} = \text{Design Flow (gpd)} \times \text{Waste Strength Adj. Factor} \times \text{Hydraulic Loading Rate } (ft^2/gpd)$$

Wastewater Strength as Sum of BOD_5 and TSS (mg/L)	Adjustment Factor
</= 30	.5
52	.6
82	.7
122	.8
175	.9
240	1.0
320	1.1
420	1.2
530	1.3
660	1.4
810	1.5
985	1.6
1180	1.7
1400	1.8
1645	1.9

1920	2.0

Both Alabama's and Florida's experience with this concept to date has been an increased awareness of wastewater quality by system designers. Florida does not plan to place organic loading criteria in rule at this point. They are using this information as guidance.

Cost Information: The cost implications of this issue are not discussed in depth in this review.

In brief, if adopted, this concept will offer an additional tool for designers to use to adequately design subsurface dispersal facilities to provide protection for public health. Designers should conduct cost/benefit analyses to determine which process (organic loading rates, pretreatment, or a combination) provides the required level of treatment at the best cost. In general, organic loading rates will require much larger land area than current hydraulic loading rates. Cost of land will obviously be a factor for most, but not necessarily for all.

Conclusions:

Based on this literature review, it is clear that organic loading is an important element in the design of infiltrative surfaces. This review supports sizing the infiltration surface so that the BOD_5 loading per unit area per unit time is equal to or less than that currently used for residential STE. However, we do not have enough information from current research about the organic loading capacity of specific soils to adopt this method into rule at this time.

Does organic strength affect loading rates? *Yes*

Should organic loading be a consideration in designing infiltrative surfaces? *Yes*

Based upon this literature review, do we have enough information to incorporate this concept into rule? *No.*

If not, then what how should a designer deal with high-strength STE? *Designers should continue to evaluate pre-treatment as a method of controlling STE strength. They also may choose to size the infiltrative surface based on organic loading as currently allowed in the "Design Standards for Large On-Site Sewage Systems". Designers of systems < 3,500 gpd may pursue a waiver to use organic loading as a design criteria.*

Other Recommendations:

- Fats, oils, and greases must be minimized in the effluent to the infiltrative surface.
- If the concentration of BOD_5 and TSS is variable, then some pretreatment may be required to control the waste strength.
- Pressure distribution should be required for this design option in order to strive for equal distribution of effluent at the design organic loading rate. However, the effect of higher waste strength on Pressure Distribution design criteria and system components is unknown.
- Prior to adopting this design tool in rule, field-testing should be conducted to evaluate the impact of high strength STE on pressure distribution systems and subsurface drip irrigation systems.
- Research should be considered to evaluate specific organic loading rates applicable to soils found in Washington State (similar to Florida study).

References:

Anderson, J., Machmeier, Sr. R., and Hansel, M. 1982. Long-Term Acceptance Rates of Soils for Wastewater. In: On-Site Wastewater Treatment: Proceedings of the Third National Symposium on Individual and Small Community Sewage Systems. ASAE. St. Joseph, MI. p. 93-100.

The rapid expansion of housing into areas not served by existing sanitary sewers resulted in a sharp increase in the number of households served by on-site systems. Disregard for proper site evaluation, design and construction of many of these systems resulted in failures and potential dangers to public health.

Research was initiated to investigate the functions of sewage treatment systems and to provide design criteria for the disposal and treatment of household wastewater.

From the results of this research, two divergent views or concepts have emerged about hydraulic capabilities of soil treatment systems. One concept is that of a long-term acceptance rate which allows the sewage treatment system to function indefinitely at its design capacity. The other concept is that of progressive or "creeping failure" which assumes that the capacity of a soil treatment system continues to decrease from the first day it is used, and "failure" is inevitable.

This paper reviewed the literature on both of these concepts. The researchers conclusions included:

- The preponderance of evidence generated by theoretical, laboratory and field studies, including those data attributed to the creeping failure concept, supports the long-term acceptance rate concept.
- Careful evaluation of soil and site factors, coupled with proper system design, construction procedures, and adequate maintenance will result in the ability to predict and maintain the acceptance rate of the soil for sewage tank effluent on a long-term basis.

Bouma, J. 1975. Unsaturated Flow During Soil treatment of Septic Tank Effluent. J. Environ. Eng. Div., ASCE 101(6): 967-983.

Crites, R., and Tchobanoglous, G. 1998. Small and Decentralized Wastewater Management Systems. McGraw Hill.

Erickson, J. and Tyler, E.J. 2001. A Model for Soil Oxygen Delivery to Wastewater Infiltration Surface. On-Site Wastewater treatment: Proceedings of the Ninth National Symposium On Individual and Small Community Sewage Systems. ASAE, St. Joseph, MI. p. 11-17.

Soil could accept onsite wastewater at rates two to three 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 system design, loading rate and life. Maintaining aerobic conditions at the wastewater infiltration surface could substantially reduce or eliminate clogging. This project is studying soil oxygen supply to the zone of clogging in soil. A model based on a form of Fick's Law for diffusive transport is being applied to oxygen diffusion to the wastewater infiltration surface. Gas filled porosity controlled by soil characteristics of texture, structure, consistence and water content as well as the distance to the supply of oxygen and rate of oxygen consumption control the flux, F, of oxygen. If the oxygen consumption rate exceeds the maximum flux of soil oxygen then the soil infiltration surface will become anaerobic. To maximize delivery of oxygen, soil components should be shallow, narrow and have separated infiltration areas. Using models that incorporate system depth, geometry, and oxygen diffusion coefficients in soil, efficient loading rates can be estimated. Design of 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.

Hargett, D.L., Tyler, E.J., and Siegrist, R.L. 1982. Soil Infiltration Capacity as Affected by Septic Tank Effluent Application Strategies. In: On-Site Wastewater Treatment: Proceedings of the Third National Symposium on Individual and Small Community Sewage Systems. ASAE. St. Joseph, MI. p. 72-84.

On-site wastewater systems utilizing soil absorption depend on the ability of the soil to absorb and purify all of the wastewater applied. Soils used for absorption of effluents may have high initial infiltration rates and more than adequate capacities to absorb the hydraulic load of wastewater. However, with continued application of effluent, a clogging layer usually develops at the infiltrative surface. This clogged zone creates a barrier to flow, restricting the rate of infiltration. Clogging is not synonymous with soil absorption system failure because flow, albeit reduced, continues through the clogged zone. Some clogging may, in fact, be regarded as an enhancement to purification.

Management of soil absorption systems with mature clogged layers infers management of this zone of reduced hydraulic conductivity. Controlling the intensity of clogging is essential to maintaining a desirable infiltration rate. Because the clogged zone controls the infiltration rate of the wastewater absorption medium, proper design requires that effluent loading not exceed the infiltration rate of the clogged system.

Major factors influencing the development and intensity of soil clogging are the pattern of the wastewater application, the loading rate, and the wastewater quality. This paper reports results of a 21-month study that examined rate and frequency of application under a controlled, replicated loading regime, yet in natural undisturbed soil conditions.

Huntzinger, D.N. 2001. Mathematical Modeling of Wastewater Soil Absorption Systems. End of Year NSF Scholarship Student Report, Department of Geology and Geological Engineering, Colorado School of Mines.

The goal of this laboratory study is to model unsaturated flow and solute transport and transformation processes associated with soil clogging genesis in soil-based wastewater treatment systems. More specifically, to generate an experimental dataset that can be used for inverse modeling of unsaturated flow and transport to estimate the soil hydraulic parameters of the clogging zone and subsoil regions over time. The results of this complex modeling can be used to develop simpler models appropriate for engineering design. The hypothesis is that the rate of development of a clogging zone and hydraulic resistance is related, in a model predictable fashion, to cumulative mass loading of biochemically oxidizable substances and suspended solids.

Jenssen, P.D. and Siegrist R.L. 1991. Integrated Loading Rate Determination for Wastewater Infiltration System Sizing, On-Site Wastewater Treatment: Proceedings of the Sixth National Symposium On Individual and Small Community Sewage Systems. ASAE, St. Joseph, MI. p. 182-191.

One of the principal parameters used in wastewater system design is the hydraulic loading rate. Historically the determination of the loading rate has been a straightforward process involving selection of a rate based on soil texture or water percolation rate. Research and experience over the past decade has provided additional insight into the complex process occurring within wastewater-amended soil systems and has suggested the fallacy of this approach. A mean grain size vs. sorting (MESO) diagram constitutes a new basis for soil classification for wastewater infiltration system design. Crude characterization of the soil hydraulic properties is possible according to the MESO Diagram and loading rate as well as certain purification aspects can be assessed from the diagram. In this paper, an approach is described based on the MESO Diagram, which integrates soil properties and wastewater pretreatment to yield a loading rate.

Kristiansen, R. 1981. The Soil as a Renovating Medium-The Fate of Pollutants in Soil – Organic Material. Proceedings of the Conference on Alternative Wastewater Treatment, Low-Cost Small Systems, Research and Development. P. 121-128.

Kristiansen, R. 1982. The Soil as a Renovating Medium-Clogging of Infiltrative Surfaces. Proceedings of the Conference on Alternative Wastewater Treatment, Low-Cost Small Systems, Research and Development. P. 105-120.

Presents an overview of research associated with the clogging layer, which develops on infiltrative surfaces in septic tank leaching systems. Discusses the three clogging phases, the causes of clogging, and the effect of loading conditions, wastewater, soil type, temperature, and redox conditions on clogging. Systems may be restored by resting.

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

A soil column experiment was designed to determine if the total weight of TSS and BOD-5 applied to the soil was directly related to soil failure or ultimate clogging. Half of the columns were loaded with septic tank effluent and the other half with extended aeration plant effluent. Results showed that TSS removal differed between the two systems, indicating that BOD-5 could be a contributing parameter in clogging. Analysis of the clogging material showed that it did not contain sufficient amounts of ferrous sulfide to be considered a major clogging component, as was previously thought. The experiment concluded that increasing the pretreatment of domestic wastewater prior to soil application increases the service time of the soil surface.

Maine, State of. 2000. 10-144 Chapter 241: Maine Subsurface Waste Water Disposal Rules, Chapter 6 - Disposal Fields.

Matejcek, B.C., Erlsten, S., and Bloomquist, D. University of Florida, 2000. Determination of Properties and the Long Term Acceptance Rate of Effluents from Food Service Establishments that Employ Onsite Sewage Treatment. Phase 2 Report for the Florida Department of Health.

Matejcek, B.C., Erlsten, S., and Bloomquist, D. University of Florida, 2001. Long Term Acceptance Rates of Common Floridian Soils. Phase 3 Report for the Florida Department of Health.

Miller, D., et al. 1994. Solids Accumulation in Recirculating Sand Filters. On-Site Wastewater Treatment: Proceedings of the Seventh National Symposium on Individual and Small Community Sewage Systems. ASAE. p 301 – 309

Solids accumulation in recirculating sand filters was investigated over a range of loading conditions using media with 3 different effective sized (ES). The rate of solids accumulation was evaluated by sacrificing identical columns at intervals for estimation of the mass of solids accumulated.

Measurement of the solids build-up on columns operated at 3 different loading rates (OLR) for up to 320-days showed accumulation at nearly uniform rate. A direct relationship was found between OLR (kg solids/ m^2 d) and the solids accumulation rate (SAR) over the four-fold range of OLR evaluated. As the ES of the media increased, the SAR decreased significantly. However, none of the loading conditions evaluated resulted in a solids equilibrium, which might allow a filter to operate indefinitely without ponding. As expected, most of the mass of the solids were found in the top layers of the filters.

This study supports organic loading rates in the range of 1.8 to 7.2 lbs. BOD_5 per 1,000 ft^2 per day, without offering any conclusions about the long-term impacts. This work indicates that, at higher OLR, solids tend to move deeper into the sand column.

Otis, R.J. 1984. Soil Clogging Mechanisms and Control. On-Site Wastewater Treatment: Proceedings of the Fourth National Symposium on Individual and Small Community Sewage Systems. ASAE. St. Joseph MI. p 238-250.

Effective control of the clogging which occurs at the soil/liquid interface due to continuous application of septic tank effluent in subsurface wastewater infiltration systems has been a long sought goal. Excessive clogging can reduce the liquid infiltration rate to a point where hydraulic failure of the system occurs while too little clogging can reduce the treatment efficiency of the system by allowing the liquid to percolate through the larger soil pores. Usually, excessive clogging is perceived as the greatest cause of subsurface infiltration system failure. Therefore, most control efforts have been directed toward reducing the resistance of the clogging zone. Many control measures have been tried but none appear to work consistently. A better understanding of the mechanisms of clogging is needed if its control is to be effected. This paper reviews studies that investigated soil clogging as a result of wastewater infiltration and explores methods for its control.

Otis, R.J. 2001. Boundary Design: A Strategy for Subsurface Wastewater Infiltration System Design and Rehabilitation. On-Site Wastewater Treatment Procedures: Proceedings of the Ninth National Symposium on Individual and Small Community Sewage Systems. ASAE. St. Joseph MI. p 245-260.

Pell, M., and Ljunggren, H. 1984. Reduction of Organic Matter with Focus on the Clogging Phenomenon. Proceedings of the International Conference on New Technology Wastewater Treatment and Sewerage in Rural and Suburb Areas, Tampere Univ of Tech., Tampere, Finland. p.311-327.

The influence of wastewater quality, especially its content of organic matter, on the clogging mechanism and the hydraulic capacity of infiltration systems was investigated. The active bacterial population and its possible adaptation to various compositions of wastewater were also studied. Small columns packed with sand were loaded once a day with an artificial septic tank effluent containing different concentrations of protein, starch or fat. Six columns loaded with protein-rich water, ranging in COD from 100 mg/l to 3200 mg/l, gave a straight-line relationship, showing that if high concentrations were dosed, larger amounts of organic matter could be accepted by the surface before ponding. It was found that the bacterial population did not adapt to the quality of the water loaded on the columns.

Ruskin, R. 1999. Are Soil Application Rates with Subsurface Drip Disposal Dependent Upon Effluent Quality? Proceedings of the Tenth Northwest On-Site Wastewater Treatment Short Course, College of Engineering, University of Washington, Seattle, 1999. p. 143 - 152.

The use of subsurface drip disposal (SSDD) of secondary treated effluent is well known and well proven in many thousands of systems both large and small. The purpose of this paper is to combine the knowledge and experience of the industry to propose guidelines for the critical factor of the sizing of the drip disposal field that will ensure safe reliable SSDD of primary and secondary treated effluent at an economic cost.

Shoemaker, D, et al. 1987. A Mathematical Model to Predict Orifice Plugging in a Low-Pressure Distribution System. On-Site Wastewater Treatment Procedures: Proceedings of the Fifth National Symposium on Individual and Small Community Sewage Systems. ASAE. p 215-223.

Design procedures for pressure distribution systems are straightforward applications of well-developed hydraulic principles. As an added complication, however, on-site systems must handle water that contains significant quantities of organic material, and vigorous colonies of microorganisms.

Thus the nature of the wastewater may cause failures in pressure distribution systems even when proper hydraulic design principles have been used.

In the system described in this paper, failures have occurred primarily due to plugging of the orifices by growth of organic matter. Thus, it is essential that the design criteria for preventing such plugging be examined.

In order to insure that low-pressure distribution systems can be designed to perform for long periods of time without failure, it was felt to be desirable to further investigate the minimum pressure head required to prevent plugging.

Thus the objectives of this paper are: 1) to describe the current research on orifice plugging being done at an existing system; 2) to describe the mathematical model being used to aid in determination of the percentage of the orifices that are plugged; and 3) to describe the efforts to determine the minimum pressure head which would be adequate to eliminate plugging problems for a particular system.

As part of this study, a mathematical model was developed to aid investigators in determining the number of unplugged orifices based on pumping pressures and pumping run times.

This study concluded that 18-ft of head (7.8 psi) was sufficient and even 15.2-ft of head (6.6 psi) appeared to be sufficient pressure to remove organic material.

Siegrist, R.L., Anderson, D.L., and Converse, J.C. 1984. Onsite Treatment and Disposal of Restaurant Wastewater. Small Scale Waste Management Project, University of Wisconsin. Madison, WI.

The design practice of household systems is often directly applied to commercial systems with little modification except for an adjustment of the design daily flow. Design and operation of commercial systems generally does not account for wastewater flow variations, organic loading, problem

wastewater constituents or other factors commonly considered in engineering other non-soil absorption wastewater facilities.

The overall objective of this work was to investigate the design and performance of septic tank-soil absorption systems for restaurant wastewaters. The specific objectives were to (1) identify the current design practice utilized for restaurant systems; (2) characterize restaurant STE in terms of daily flow and composition; (3) determine the operation status and infiltration capacity of a sample of restaurant soil absorption systems; (4) compare the infiltration and purification through soil of restaurant STE versus household STE; and (5) develop modifications as appropriate to presently used design practice to facilitate successful performance of restaurant systems.

Siegrist, R.L., Anderson, D.L., and Converse, J.C. 1985. Commercial Wastewater Onsite Treatment and Disposal. On-Site Wastewater Treatment Procedures: Proceedings of the Fourth National Symposium on Individual and Small Community Sewage Systems. ASAE. St. Joseph MI. p 210-219.

As part of the Small Scale Waste Management Project, an investigation was undertaken into the design and performance of septic tank soil absorption systems for commercial wastewaters. Of particular interest were restaurant facilities, as on-site systems serving several of these had exhibited exceptionally poor performance. The objectives of the study were to characterize commercial septic tanks effluents, determine the design and operational characteristics of commercial soil absorption systems, and develop modifications as appropriate to household system design and operation practices to enhance commercial system performance.

Siegrist, R.L. 1987. Hydraulic Loading Rates for Soil Absorption Systems Based on Wastewater Quality. On-Site Wastewater Treatment: Proceedings of the Fifth National Symposium on Individual and Small Community Sewage Systems. ASAE. St. Joseph MI. p 232-241.

Process design of soil absorption systems requires selection of various parameters whose relationships to soil pore clogging are not well defined. The applied wastewater quality and loading rate are two parameters that can be controlled through wastewater pretreatment or soil system sizing. Prior research has shown that soil clogging is generally accelerated under increasing hydraulic loading rates of a given wastewater effluent, or under increasing concentrations of organic matter and suspended solids at a given hydraulic loading rate. Nevertheless, common design practice has been to neglect consideration of wastewater quality and simply apply STE to soil absorption systems at 1 to 5 cm/day (0.245 to 1.225 gpd/ft^2), with the rate based solely upon natural soil properties (e.g. US EPA, 1980). Unfortunately this design approach has led to hydraulic dysfunction and diminished wastewater renovation in some systems, including commercial and community-scale facilities, and has precluded effective use of wastewater pretreatment concepts.

There is growing evidence from research and practical experience that supports a soil absorption system design practice which accounts for wastewater effluent quality as well as hydraulic loading. The purpose of this paper is to examine wastewater effluent quality as a factor in soil absorption system design and to discuss as alternative approach to conventional design practice.

Siegrist R.L. and Boyle W.C. 1987. Wastewater Induced Soil Clogging Development, Journal of Environmental Engineering. ASCE. Vol. 13(3). P 550-566.

The development of wastewater-induced soil clogging in subsurface wastewater infiltration systems is investigated in the field over a 70-month period. Domestic septic tank effluent (DSTE), graywater septic tank effluent (GSTE), and tapwater (TW) are intermittently applied at 1.3, 2.6, and 5.2 cm/day to replicate 0.9-m diameter pilot-scale wastewater infiltration systems installed in situ in a structured silty clay loam subsoil. Soil clogging development is negligible under all TW loadings and under GSTE loadings at 1.3 and 2.6 cm/day. Under GSTE loadings at 5.2 cm/day and under all DSTE loadings severe soil clogging development leads to continuous ponding of the soil infiltrative surfaces. A logistic model fit to the experimental data confirms that soil clogging development is highly correlated with the cumulative mass density loading of total biochemical oxygen demand and suspend solids (R^2=0.95). Wastewater composition as well as hydraulic loading rate need to be considered in system design and management.

Siegrist, R.L. 1987a. Soil Clogging During Subsurface Wastewater Infiltration as Affected by Effluent Composition and Loading Rate, Journal of Environmental Quality, 16(2): 181-187.

The soil clogging effects of wastewater effluent composition and loading rate were investigated in pilot-scale infiltration cells installed in situ in the structured silty clay loam subsoil of a Typic Argiudoll (fine-silty, mixed, mesic). Over a 70-month period domestic septic tank effluent (DSTE), graywater septic tank effluent (GSTE) and tap water (TW) were intermittently applied in an average of 5.2 doses/d to yield daily loading rates of 1.3, 2.6, and 5.2 cm/d. Soil clogging was negligible in all TW treatments and in the GSTE treatment at 1.3 and 2.6 cm/d. In the GSTE treatment at 5.2 cm/d and in all DSTE treatment, severe soil clogging led to continuous ponding of the soil infiltrative surfaces. A logistic model fit to the experimental data confirmed that soil-clogging development was highly correlated with the cumulative mass density loadings of total biochemical oxygen demand and suspended solids. After 62 and 70 months of loading, soil properties were determined with depth. Clogged infiltrative surface zones exhibited significant accumulations of organic materials at the infiltrative surface and within the first few millimeters of the soil matrix. This field study demonstrated that higher quality wastewater effluents can be discharged to subsurface infiltration systems at hydraulic loading rates in excess of those utilized for DSTE without stimulating soil clogging development.

Siegrist, R.L. 2000. Designs and Performance of Onsite Wastewater Soil Absorption System. National Needs Conference, Risk-Based Decision Making for Onsite Wastewater Treatment, Washington University, St. Louis, MO.

The primary system for onsite and decentralized wastewater treatment in the U.S. includes septic tanks pretreatment followed by subsurface infiltration and percolation through the vadose zone prior to recharge of the underlying ground water. These wastewater soil absorption systems (WSAS) have the potential to achieve high treatment efficiencies over a long service life at low cost, and be protective of public health and environmental quality. Favorable results from lab and field studies as well as the absence of documented adverse effects suggest that system design and performance are generally satisfactory. However, the understanding and predictability of performance as a function of design, installation/ operation, and environmental factors, as well as the risk of inadequate function and its effects, have not been fully elucidated. This has been due to the complex and dynamic relationships between hydraulic and purification processes and the factors that control their behaviors. As a result, the current state-of-knowledge and standard-of-practice have gaps and shortcomings that can preclude rational system design to predictably and reliably achieve specific performance goals. Moreover, the quantitative analysis of long-term treatment efficacy on a site-scale up to watershed scale is difficult, as is any formal assessment of risks and selection of appropriate management actions. This white paper describes the process function and performance of WSAS. The system performance capabilities and predictability as well as reasonably conceivable system dysfunctions are described within a risk assessment and management framework. Issues applicable to the single-site scale and to the multiple-site to watershed scales are addressed. Based on an analysis of the current state-of-knowledge, critical research needs are identified and prioritized. As described herein, critical questions and current gaps in knowledge generally relate to the absence of fundamental process understanding that enables system performance relationships to be quantified and modeled for predictive purposes. High and very high priority research needs include those that support: (1) fundamental understanding of clogging zone genesis and unsaturated zone dynamics and their effects on treatment efficacy, particularly for pathogens, (2) development of modeling tools for predicting WSAS function and performance as affected by design and environmental conditions, (3) identification of indicators of performance and methods of cost-effective monitoring, and (4) development of valid accelerated testing methods for evaluating long-term WSAS performance.

South Carolina Bureau of Water Pollution Control. 1990. Guidelines for Unit Contributory Loadings to Wastewater Treatment Facilities.

Stuth, B., and Guichard, M. 1989. Managing Grease & Oil in Restaurant Waste. Proceedings of the Sixth Northwest On-Site Wastewater Treatment Short Course, College of Engineering, University of Washington, Seattle, 1989. p. 98 - 113.

Stuth, B. 1992. Treating Commercial High-Strength Waste. Proceedings of the Seventh Northwest On-Site Wastewater Treatment Short Course, College of Engineering, University of Washington, Seattle, 1992. p. 66 - 79.

Report is based on findings from years of monitoring residential and commercial sewage treatment and disposal systems.

Stuth, B. and Garrison, C. 1995. An Introduction to Commercial Strength Wastewater. Proceedings of the Eighth Northwest On-Site Wastewater Treatment Short Course, College of Engineering, University of Washington, Seattle, 1995. p. 380 - 395.

Texas On-Site Insights. 2001. Texas A&M – Kingsville Evaluates Performance of Subsurface Drip for On-Site Wastewater Systems. R. Jensen, Editor. Volume 10, Issue 1.

Tyler E.J., and Converse J.C. 1989. Hydraulic Loading Based Upon Wastewater Effluent Quality, Proceedings of the Sixth Northwest On-Site Wastewater Treatment Short Course, College of Engineering, University of Washington, Seattle, 1989. p. 163-172.

Reducing the absorption area for on-site wastewater infiltration systems by increasing the long term loading rate is a goal of many working with soil wastewater absorption systems. Higher wastewater loading rates might be attained by selecting more permeable soil or by reducing the soil clogging resistance. Selecting a different soil, particularly on small lots, may be impossible and therefore reduction of the soil clogging resistance is the only method of reducing infiltration area. One method to achieve long term reduced clogging resistance may be to improve applied wastewater effluent quality.

Increasing the loading rate reduces the residence time of the wastewater in the soil. Therefore, longer travel distance or separation distances may be needed to reach acceptable treatment. However, reduced residence time may be compensated for by the improved wastewater quality achieved from pretreatment. Since the primary objective of on-site wastewater disposal systems is to treat wastewater, these objectives must be attainable before using higher loading rates.

This paper demonstrates that pretreated effluent of high quality can be applied at higher rates than septic tank effluent. It also states that it is impossible to predict effluent loading rates for intermediate strengths of pretreated wastewater strengths.

Tyler E.J., and Converse J.C. 1984. Soil Evaluation and Design Selection of Large or Cluster Wastewater Soil Absorption Systems. On-Site Wastewater treatment: Proceedings of the Fourth International Symposium On Individual and Small Community Sewage Systems. ASAE. St. Joseph, MI. p. 179-190.

Tyler E.J., Converse J.C., and Keys. J.R. 1995. Soil Acceptance of Wastewater Affected by Wastewater Quality, Proceeding of the Eighth Northwest On-Site Wastewater Treatment Short Course, College of Engineering, University of Washington, Seattle, 1995. p. 96-109.

Reducing organic materials with wastewater pretreatment systems reduces soil pore plugging and has the potential for higher long-term infiltration or loading rates. Loading rates of pretreated wastewater in sands can be increased more than in clayey soil. Wastewater loading rates are suggested considering wastewater quality and soil factors. Rates for highly pretreated wastewater might be 2 to 16 times greater than rates recommended for septic tank effluent. Higher loading rates, however, reduce the wastewater retention time and therefore wastewater treatment in soil. In the event a pretreatment system fails to deliver highly pretreated wastewater to the soil, it is likely that a rapid hydraulic failure of the soil system will occur.

U.S. EPA . 1980. Onsite Wastewater Treatment and Disposal Systems: Design Manual. EPA 625/1-80-012. U.S. EPA, Cincinnati, OH.

U.S. EPA . 1992. Manual – Wastewater Treatment/ Disposal for Small Communities. EPA 625/R-92/005.

U.S. EPA . 1999. The Class V Underground Injection Control Study – Volume 5, Large Capacity Septic Systems. EPA 816-R-99-014e.

WA. State Department of Ecology. 1999. Criteria for Sewage Works Design.

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