RULE DEVELOPMENT COMMITTEE ISSUE RESEARCH REPORT

- LINEAR LOADING RATES -

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Topic & Issues:

Linear Loading Rates

Initial topic:

- So that soil absorption components deliver no more than the receiving soil can transmit away from the site, maximum linear loading rates should be established based on the depth of soil, soil morphology and the gradient of the slope.

Additional Questions:

- Are linear loading rates an important part of designing systems?
- Should we include linear loading rates in Washington's design requirements?
- If yes, how should we include this factor?

Summary:

Linear loading rate is a concept that has had some intuitive recognition for many years and has been formally developed over the past 20 years. This review provides a definition, a description of the variables that determine it, and summarizes the current status of this concept. One of the pioneers of this concept has created a table that relates linear loading rate to soil morphology, the depth of permeable soil and the slope of the impervious soil horizon. All of the research concludes that the linear loading rate is a critical design element for onsite sewage systems whenever there is a restriction to the vertical movement of water in the soil.

KEYWORDS: linear loading rate, linear loading

Introduction:

In Washington state a requisite site determination for designing an on-site sewage system is the infiltration rate into the native soil based on an analysis of soil features and the characteristics of the applied effluent. What is not usually required for design is a determination of the rate of transmission of the infiltrated water through the soil away from the infiltration surface when a vertical flow restriction is present. This latter flow characteristic is called the linear hydraulic loading rate, and depends on the characteristics of the soil, the depth of the permeable soil horizons and the slope. Linear loading rate is defined as the loading rate per linear foot of system (gallons per day per linear foot) along the contour.

Linear loading rates are rarely a limiting factor in on-site system design when generous soil depths are present. However, they are often a limiting factor when permeable soils are shallow enough to require the use of mound, at-grade or Glendon technologies.

The purpose of this review is to summarize the scientific literature on the topic of linear hydraulic loading rates and where and how this concept should be applied to the design of on-site sewage systems. Fourteen publications were collected and reviewed. These publications included peer-reviewed journal articles, other journal articles and conference proceedings. Conference proceedings comprise the largest group of publications, and even though they are not typically peer-reviewed, they provide useful information. In addition, many of the authors are recognized scientific experts in the field of on-site sewage treatment and dispersal.

Body:

The concept of linear loading rate has been indirectly addressed in on-site sewage designs for many years. Designers and regulators have known intuitively that a series of short drainfield lines stacked on a slope is a poor design concept and invites surfacing sewage in the downslope area. Design criteria for mounds (a technology used when shallow soils and high ground water tables are present) call for shaping the mound long and narrow, with the long axis along the site contour. Long and narrow designs have also been specified when slowly permeable soils overlay impermeable horizons.

Discussion of linear loading rates first began appearing in the literature with regards to large or cluster wastewater absorption systems. Tyler and Converse (1984) describe linear loading rates as being important design criteria for large systems from which system width and length are calculated. Tyler, Converse and Parker (1985) discussed linear loading rate and introduced another parameter: BOD linear loading rate. They illustrated their presentation with two examples where these parameters are calculated and utilized. Their examples argue for narrow system widths. From observations in an experimental program where mound systems were placed on properties with failing on-site systems, Converse and Tyler (1987) showed that mounds can be placed on much more restrictive sites if the system is designed using linear loading rates that fit the site and if the installer follows correct construction and siting procedures.

In their work to describe the siting, design, construction and performance of the Wisconsin at-grade system, Converse, Tyler and Peterson (1987) incorporate linear loading criteria published in earlier works. An at-grade system is a technology developed to overcome some site conditions that restrict the use of in-ground soil absorption systems. They point out that where restrictive subsurface boundaries or surface horizons of lower infiltrative rates are encountered, “the linear loading rate should be reduced and absorption widths of 1 to 1.5 meters (3 to 5 feet) are more appropriate.” Christopher (1988) offers equations to calculate the linear loading rate for a given site.

Converse, Tyler and Peterson (1990) say that the linear loading rate (LLR) can be greater for deep permeable soils than for a shallow zone of permeable soil over a less permeable soil. However, they say it is difficult to estimate the LLR for many soil conditions. They do offer that if the flow away from the system is primarily vertical, then the LLR can be high but should be limited to 10-gpd/linear foot. If the more permeable soils are shallow, and the flow away from the system is primarily horizontal, then the LLR should be constrained to 3-4-gpd/linear foot.

Based on experience, Tyler and Kuns (2000) describe linear loading rates as an element of design and offer a table for use in designing that factors in soil descriptions, infiltration loading rate, slope, and infiltration distance. They point out that the values are based on experience and they need to be verified or adjusted based on further research and testing. These authors also include a case study from Lake County, Ohio, where the table is used in the design of systems in areas where high water tables are experienced during part of the year and where trench type systems have a failure rate as high as 35%. A reproduction of the table is shown below (Table 1). Tyler (2001) develops this tabular concept of linear loading rates even further.

Tyler (2001) describes that both the length and the width of an absorption system are determined by the hydraulic linear loading rate. The length is the wastewater volume (gal/day) divided by the linear loading rate (gal/linear ft./day). The width is linear loading rate (gal/linear ft./day) divided by the soil infiltration loading rate (gal/ft^2/day).

Table 1. Infiltration rates in gal/d/ft^2 for wastewater of >30 mg L^{-1} or wastewater of <30 mg L^{-1} and hydraulic linear loading rates in gal/d/ft for soil characteristics of texture and structure and site conditions of slope and infiltration distance. Values assume wastewater volume of >150 gal/d/bedroom. If horizon consistence is stronger than firm or any cemented class or the clay mineralogy is smectitic, the horizon is limiting regardless of other soil characteristics. {© 2000 by E. Jerry Tyler, printed with permission}.

Soil characteristics			Infiltration loading rate, gal/da/ft^2		Hydraulic linear loading rate, gal/d/ft								
					Slope								
					0-4%			5-9%			>10%		
					Infiltration distance, inch			Infiltration distance, inch			Infiltration distance, inch		
Texture	Structure		>30 mg/L BOD	<30 mg/L BOD	8-12	12-24	24-48	8-12	12-24	24-48	8-12	12-24	24-48
	Shape	Grade											
COS, S, LCOS, LS	--	0SG	0.8	1.6	4.0	5.0	6.0	5.0	6.0	7.0	6.0	7.0	8.0
FS, VFS,LFS,LVFS	--	0SG	0.4	1.0	3.5	4.5	5.5	4.0	5.0	6.0	5.0	6.0	7.0
CSL, SL	--	0M	0.2	0.6	3.0	3.5	4.0	3.6	4.1	4.6	5.0	6.0	7.0
	PL	1	0.2	0.5	3.0	3.5	4.0	3.6	4.1	4.6	4.0	5.0	6.0
		2, 3	0.0	0.0	-	-	-	-	-	-	-	-	-
	PR/BK /GR	1	0.4	0.7	3.5	4.5	5.5	4.0	5.0	6.0	5.0	6.0	7.0
		2,3	0.6	1.0	3.5	4.5	5.5	4.0	5.0	6.0	5.0	6.0	7.0
FSL, VFSL	--	0M	0.2	0.5	2.0	2.3	2.6	2.4	2.7	3.0	2.7	3.2	3.7
	PL	1,2,3	0.0	0.0	-	-	-	-	-	-	-	-	-
	PR/BK /GR	1	0.2	0.6	3.0	3.5	4.0	3.3	3.8	4.3	3.6	4.1	4.6
		2,3	0.4	0.8	3.3	3.8	4.3	3.6	4.1	4.6	3.9	4.4	4.9
L	--	0M	0.2	0.5	2.0	2.3	2.6	2.4	2.7	3.0	2.7	3.2	3.7
	PL	1,2, 3	0.0	0.0	-	-	-	-	-	-	-	-	-
	PR/BK /GR	1	0.4	0.6	3.0	3.5	4.0	3.3	3.8	4.3	3.6	4.1	4.6
		2, 3	0.6	0.8	3.3	3.8	4.3	3.6	4.1	4.6	3.9	4.4	4.9
SIL	--	0M	0.0	0.2	2.0	2.5	3.0	2.2	2.7	3.2	2.4	2.9	3.4
	PL	1,2,3	0.0	0.0	-	-	-	-	-	-	-	-	-
	PR/BK /GR	1	0.4	0.6	2.4	2.7	3.0	2.7	3.0	3.3	3.0	3.5	4.0
		2,3	0.6	0.8	2.7	3.0	3.3	3.0	3.5	4.0	3.3	3.8	4.3
SCL,CL SICL	--	0M	0.0	0.0	-	-	-	-	-	-	-	-	-
	PL	1,2,3	0.0	0.0	-	-	-	-	-	-	-	-	-
	PR/BK /GR	1	0.2	0.3	2.0	2.5	3.0	2.2	2.7	3.2	2.4	2.9	3.4
		2,3	0.4	0.6	2.4	2.9	3.4	2.7	3.0	3.3	3.0	3.5	4.0
SC, C, SIC	--	0M	0.0	0.0	-	-	-	-	-	-	-	-	-
	PL	1,2,3	0.0	0.0	-	-	-	-	-	-	-	-	-
	PR/BK /GR	1	0.0	0.0	-	-	-	-	-	-	-	-	-
		2,3	0.2	0.3	2.0	2.5	3.0	2.2	2.7	3.2	2.4	2.9	3.4

Cost Information (if available & applicable):

Conclusions:

- Hydraulic linear loading rates are a key design element when on-site systems are sited where there is a soil layer with very limited permeability or where there is a shallow ground water table. Under these conditions, an on-site system relies on horizontal movement of the water away from the infiltrative surface. This horizontal movement must equal or exceed the rate at which wastewater is infiltrated plus the additions from rainwater.

- Horizontal movement is dependent on the characteristics of the soil, the depth of the permeable soil and the slope of the impermeable subsurface horizon. Limiting the width of the system and extending the length along the contour can control loading of each linear foot of native soil along the contour. When using linear loading rates in system design, the following relationships are used:

$$Length = \frac{Daily\,Design\,Flow}{Linear\,Loading\,Rate} \qquad Width = \frac{Linear\,Loading\,Rate}{Soil\,Loading\,Rate}$$

- Tyler has led an effort to develop the relationship of linear loading to soil characteristics, permeable soil depth, and slope of the site, and has promoted the concept as crucial when designing on shallow soils, where the movement of water away from a soil infiltration system is primarily horizontal. These relationships are presented in Table 1, with preliminary values that need refinement with research and testing.

References

Benson, RA, Griffith, CM. 2001. Modified Mounds On Soils With Slow Permeability And Shallow Seasonal Water Tables, Proceedings of the Ninth Symposium on Individual and Small Community Sewage Systems, ASAE, St. Joseph, MI. Pp. 215-224.

Very slow permeability and shallow seasonal water tables are among the soil conditions that limit the ability of leaching trenches to renovate domestic wastewater in Clermont County, southwest Ohio. The Wisconsin Mound, which has been used in the county since 1985, compensates for these soil conditions to provide renovation, but has not been a popular alternative due to the size of the mound required. Low profile modified mounds in combination with four types of secondary treatment technology, including fixed film aerobic treatment, intermittent sand filtration, peat filtration and suspended growth aerobic treatment, are being offered to Health District residents as alternatives to the Wisconsin Mound. A study to be completed in Winter 2000/2001 is examining systems installed on very poorly drained Clermont Silt Loam soil. Raw influent, secondary effluent prior to soil application, and water from a gradient drain at the perimeter of the modified mounds are being sampled and tested for Fecal Coliform, TSS, BOD5, NH3, and Total-P. Preliminary sampling data indicate that these modified mound designs may provide excellent renovation of domestic wastewater on Clermont Silt Loam soil.

Christopher, D. 1988. Linear Loading Rate, Submitted for partial completion of course ESE 651, University of Wisconsin, Madison. Instructor: RK White. 9 pages.

The linear loading rate is an important element in soil absorption system design. Most of the literature surrounding this topic refers directly to the importance of the linear loading rate (LLR) as it relates to the design of a mound system. The EPA Design Manual for Onsite Wastewater Treatment and Disposal Systems mentions both horizontal and vertical water movement, which is a key element in the determination of the LLR, but it has no reference to specific calculations of the linear loading rate. This article is an attempt to present information on the characteristics, design, soil information, and calculations need to determine the linear loading rate.

Converse, JC, Kean, ME, Tyler, EJ, Peterson, JO. 1991. Bacterial and Nutrient Removal in Wisconsin At-Grade On-Site Systems, Proceedings of the 6th National Symposium on Individual and Small Community Sewage Systems, ASAE, St. Joseph, MI. Pp. 46-61.

The Wisconsin at-grade wastewater soil absorption system was developed for sites that do not meet the minimum separation distances for conventional in-ground systems but exceed the requirements for mound systems. Converse et al. (1989) presents the concepts and design of the at-grade unit. A manual was developed to assist professionals in siting, designing and constructing Wisconsin at-grade systems. Currently there are several hundred at-grade systems installed in Wisconsin. Initially evaluation of the at-grades was based on hydraulic performance with the assumption that treatment performance would be similar to in-ground systems. The objective of this research was to evaluate the bacterial and nutrient removals from wastewaters in the soils beneath at-grade systems under actual field situations.

Converse, JC, Kean, ME, Tyler, EJ, Peterson, JO. 1992. Nitrogen, Fecal Coliforms and Chlorides Beneath Wisconsin At-Grade Soil Absorption Systems, Proceedings of the 7th Northwest On-Site Wastewater Treatment Short Course and Equipment Exhibition, University of Washington, Seattle, WA. Pp. 105-123.

Environmental awareness of ground water contamination by on-site wastewater disposal systems is increasing and implementation of new ground water protection laws call for closer scrutinizing of treatment effectiveness for fecal coliforms as well as for viruses, nitrogen, chlorides and possibly a host of other contaminants. Advances have been made in on-site technology with the development of new soil absorption systems, such as mounds and at-grade systems, to meet more restrictive site conditions. New developments for pretreatment of wastewater, such as sand filters and aerobic units, have contributed to improved effluent quality and may improve infiltration into some soils. This study was undertaken to evaluate the levels of nitrogen, fecal coliform bacteria and chlorides beneath Wisconsin at-grade soil absorption systems which receive effluent from septic tanks or other pretreatment systems, such as aerobic units and sand filters and applied to the at-grade unit by pressure or gravity distribution.

Converse, JC, Tyler, EJ. 1987. On-Site Wastewater Treatment Using Wisconsin Mounds on Difficult Sites, TRANSACTIONS of the American Society of Agricultural Engineers, 30(2):362-368 (March/April).

The Wisconsin mound system, using relatively conservative soil criteria, has been accepted by many states as an alternative for sites not suitable for the in-ground soil absorption system. An experimental program was initiated in 1978 to evaluate soil site limitations for the Wisconsin mound by installing full size units on home sites with failing systems. Based on evaluation of over 40 systems, 11 of which are described in detail, mounds can be placed (a) on sites with high water tables approaching 25 cm of the surface, (b) on slowly permeable soils with permeabilities in the moderately low to low categories, (c) on slopes up to 20-25%, (d) over existing in-ground systems, and (e) on filled sites. The performance of the sites has been very good. During extremely wet weather on the more slowly permeable soil, there may be some leakage at the toe of the mound. The quality of the leakage is very good with very low fecal coliform counts. Mounds can be placed on much more restrictive sites if the system is designed using linear loading rates that fit the site and if correct construction and siting procedures are followed.

Converse, JC, Tyler, EJ. 1998. Soil Dispersal of Highly Pretreated Effluent – Considerations for Incorporation into Code, Proceedings of 7th Annual Conference, National On-site Wastewater Recycling Association (NOWRA), Northbrook, IL. Pp. 42-49.

The primary role of the septic tank for treating domestic wastes is to remove settleable and floatable solids with the soil providing the treatment and dispersal into the environment. Soil loading rates and separation distances for septic tank effluent have been established for various soil and site conditions with typical loading rates in the range of 0.2 - 0.8 gpd/ft^3 and separation distances ranging from <1 to >4 ft. Higher wastewater loading rates to the soil and smaller separation distances from the infiltrative surface to groundwater or bedrock are possible if more advanced pretreatment units than a septic tank are used. These advanced pretreatment units, such as sand filters, recirculating sand filters, peat filters or aerobic treatment units (ATU), reduce BOD, TSS and bacteria allowing higher loading rates and lower separation distances than if septic tank effluent is applied directly.

The objectives of this paper are: 1) to summarize several research studies relating to a) treatment performance of three types of pretreatment units and b) soil dispersal of highly pretreated effluent, and 2) to discuss how the results may be interpreted for incorporation into code.

Converse, JC, Tyler, EJ, Peterson, JO. 1987. The Wisconsin At-Grade Soil Absorption System for Septic Tank Effluent, Proceedings of the 5th Symposium on Individual and Small Community Sewage Systems, ASAE, St. Joseph, MI. Pp. 180-192.

The Wisconsin at-grade soil absorption system was developed to overcome some site conditions that restrict the use of in-ground soil absorption systems and to reduce the need for a Wisconsin mound system. This paper describes the siting, design, and construction of the Wisconsin at-grade system and reports performance.

Converse, JC, Tyler, EJ, Peterson, JO. 1990. Wisconsin At-Grade Soil Absorption System: Siting, Design, and Construction Manual, Small Scale Waste Management Project, University of Wisconsin, Madison. January 1990. 41 pages. Revisions added January 1992. [This paper is a revision of a paper by same title, in Proceedings 6th Northwest Onsite Wastewater Treatment Short Course, University of Washington, Seattle, Sept. 1989. Pp. 146-162.]

The Wisconsin At-Grade Soil Absorption system is one of several soil absorption systems that can be used to treat and dispose of on-site wastewater through the soil. It is a relatively new system with the first system installed in 1982. Since that time a number of systems have been installed and it appears that this system has a lot of promise on sites that don't meet the criteria for in-ground soil absorption systems but exceed the criteria for the Wisconsin Mound System. The siting, design and construction of the Wisconsin at-grade soil absorption system is presented including system configurations, distribution networks, and sizing of the system for effective absorption area. Included is a design and construction example for the at-grade system and for a pressure distribution network that can be used with the at-grade soil absorption system.

EPA 2002. On-site Wastewater Treatment Systems Manual, Environmental Protection Agency, Office of Water, EPA/625/R-00/008. 367 pages.

There are several references to linear loading in this document, especially in regards to design geometry.

Tyler, EJ. 2001. Hydraulic Wastewater Loading Rates To Soil, Proceedings of the Ninth Symposium on Individual and Small Community Sewage Systems, ASAE, St. Joseph, MI. Pp. 80-86.

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

Tyler, EJ, Converse, JC. 1984. Soil Evaluation and Design Selection for Large or Cluster Wastewater Soil Absorption Systems, Proceedings of the Fourth Symposium on Individual and Small Community Sewage Systems, ASAE, St. Josephs, MI. Pp. 179-190.

An effort is made to apply soil evaluation information to the design of two large wastewater soil absorption systems instead of substituting guidelines and rules for small systems. Site evaluation established surface water conditions, infiltration rate, vertical and horizontal saturated hydraulic conductivity, unsaturated hydraulic conductivity for the clogging layer, zones of permanent and perched water tables, and groundwater conditions for each of the soil horizons present. A Certified Soil Tester as designated by the State of Wisconsin performed evaluations and two test systems were installed to test the design concepts. Monitoring data will be forthcoming. Conceptual models indicate that the width of the infiltrative surface and linear loading rates are important design criteria. (AU/SWF)

Tyler, EJ, Converse, JC, Parker, DE. 1985. Soil Systems for Community Wastewater Disposal – Treatment and Absorption Case Histories, Proceedings of a Workshop on Utilization, Treatment, and Disposal of Waste on Land, Soil Science Society of America, Madison, WI. Pp. 147-158.

A review of the configuration and function of soil absorption systems is given, followed by design concepts, and presentation of two case histories. Wastewater, chemical, microbial, and gas movement are outlined. The concepts of linear loading rate (LLR) and BOD linear loading rate (BLLR) are introduced. The calculation and application of these parameters are illustrated. Application of the LLR and BLLR shows that system widths should be minimized. Three subsurface soil absorption cells, each 30 m wide, were put into service in Kingston, Wisconsin, in 1981. All three beds have ponded wastewater within the distribution network and have, at times, exhibited surface failure. Low oxygen levels and elevated levels of carbon dioxide and methane have been detected in the soil beneath the system. No groundwater mounding has occurred. 6 mounds, each 4.6 m wide, used on a rotating basis, were designed and constructed in Wisconsin using the LRR concept. No ponding in the beds has been evident after two years of operation. (SWF)

Tyler, EJ, Kuns, LK. 2000. Designing with Soil: Development and Use of a Wastewater Hydraulic Linear and Infiltration Loading Rate Table, Proceedings of 9th Annual Conference, National On-site Wastewater Recycling Association (NOWRA), Northbrook, IL. 7 pages between Pp. 90 & 91.

Wastewater infiltration loading rates are estimated based on the wastewater quality and soil characteristics related to soil pores. Hydraulic linear loading rates are estimated based on soil characteristics related to soil pores and to the depth and slope of horizontally moving water. A table to derive design wastewater infiltration and hydraulic linear loading rates from field determined soil and site characteristics is used for soils with vertical flow restricting horizons. Wastewater infiltration systems installed in soils with vertical flow restricting horizons in Lake County, Ohio were recently found to be failing at an unacceptable rate. County Health District staff studied potential designs and soil site evaluation procedures. As a result of these efforts successful experimental systems have been installed using soil and site information to estimate the design infiltration rate and hydraulic linear loading rate.

Wespetal, MS. 2001. Alternative Design for Mound Systems - Vertical Sidewall Mounds, Proceedings of the 9th Symposium on Individual and Small Community Sewage Systems, ASAE, St. Joseph, MI. Pp. 261-270.

Mound systems are used to overcome limitations imposed by seasonally saturated soils or bedrock. Mound systems are essentially a single pass, open bottom sand filter that provides both treatment and disposal of sewage tank effluent. Mound systems have proven to adequately treat and dispose of sewage in a reliable, cost-effective manner. However, mounds have been criticized, mainly by the public, for the large footprint required, poor aesthetics and the unusable lawn area resulting from the sharp rise in elevation. In addition, many existing sites with a seasonally saturated soil are too small to support the large footprint required for mound systems. To overcome these problems an alternative mound design is proposed that requires less footprint area and is more aesthetically pleasing. This vertical sidewall mound design is based on the perceived over-design of the absorption area and the additional unnecessary area needed to accommodate mound side-slopes. Evaluation of the standard mound design shows that the theory of pretreatment has not been applied. Specifically, the mound rock bed is designed on the development of a clogging mat and is sized at 5 cm/day (50 liters/meter 2) in Minnesota. As the effluent passes out of the rock bed and into the sand, the BOD and TSS levels are substantially reduced, therefore a biological clogging mat should not form at the absorption area at the sand/natural soil interface. However the sizing of the absorption area accounts for a development of a clogging mat. An examination of the literature indicates that the absorption area for pretreated effluents is similar to what is required for a mound rock bed. Therefore, in theory, a mound with vertical sidewalls should hydraulically function. Two types of vertical sidewall mounds were constructed and observed in Minnesota by licensed professional designers and installers. These vertical side wall mounds are much smaller and have enhanced aesthetics. This paper presents the theory behind the vertical sidewall mound, design parameters, construction methods and observations of performance by licensed professionals in Minnesota.