HYDRAULIC WASTEWATER LOADING RATES TO SOIL

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ABSTRACT

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.

KEYWORDS: Septic systems, Wastewater infiltration, Wastewater loading, Soil water flow, Linear loading rate.

INTRODUCTION

The rate wastewater infiltrates soil from wastewater infiltration systems is limited by clogging layers and controlled by the nature of both the clogging layer and the soil (Bouma, 1975). Once in the soil, the added water must continue to move away from the infiltration surface. This flow is independent of the nature of the clogging layer and only dependent on the nature of the soil. Water moves away from the system following the water potential gradients. In soils with flow restrictions, water movement may become horizontal. Water movement away from the infiltration surface must be greater than the wastewater infiltration rate or the system will fail.

There have been many estimates of wastewater infiltration rates into soil. Infiltration rates for domestic wastewaters from septic tanks assuming around 570 L d^{-1} per bedroom (150 gpd/bedroom) are most frequently reported. Values are based primarily on experience. Some reported septic effluent rates have been reviewed by Keys, et. al 1998. Suggested infiltration rates for domestic wastewaters with reduced biochemical oxygen demand (BOD) are less common (Siegrist, 1987 and Tyler and Converse, 1994).

Hydraulic linear loading rate is the volume of wastewater that the soil surrounding a wastewater infiltration system can transmit far enough away from the infiltration surface such that it no longer influences the infiltration of additional wastewater. The concept of hydraulic linear loading rate was first introduced by Tyler and Converse (1984). Since that time, there

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has been little done to assign possible design values for hydraulic linear loading rate; however, limits have been put on infiltration width in an attempt to limit the hydraulic linear loading rate.

Therefore, a procedure to estimate values for hydraulic linear loading rates based on soil characteristics is needed. Since wasterwater infiltration rates are also based on soil characteristics the procedure should include wastewater infiltration rates and present the two design values together.

OBJECTIVES

1. Define wastewater infiltration into soil and water flow away from wastewater infiltration systems and
2. Present a procedure to estimate wastewater infiltration and hydraulic linear loading rates based on soil characteristics assuming a wastewater quality and volume.

WASTEWATER LOADING RATES

Wastewater movement into and through the soil depends on the interaction of the wastewater with the soil to create a clogging layer and on the hydraulic properties of the soil. Each type of flow is defined separately and the limiting flow is used for design.

Infiltration Loading Rates

Wastewater infiltration or loading rates define the rate wastewater enters the soil. When applying septic tank effluent, a clogging layer forms at the infiltrative surface. Clogging layers impede water infiltration and reduce the loading applied to far below the maximum infiltration rate of unclogged soil. Bouma (1975) explained the basis of wastewater infiltration into clogged soil. Since the water that passes the clogging layer also percolates through the soil then:

$$Q_c = Q_s = K_c \frac{(H_o + \Psi + z_c)}{z_c}$$

where Q_c is the flow through the clogging layer, Q_s is the wastewater flow through the soil, K_c is the hydraulic conductivity of the clogging layer, H_o is the wastewater ponding height above the infiltrative surface, Ψ is the soil moisture potential in the soil just outside the clogging layer and z_c is the thickness of the clogging layer. Wastewater infiltration into soil is dependent on the character of both the clogging and soil. Since soil is a factor in infiltration rate through a clogging layer, wastewater loading rates will vary from soil-to-soil with the same clogging. The differences in wastewater infiltration rates are related to soil characteristics defining pore sizes and pore size distribution. Texture, structure, and consistence each contribute information about soil pores. Also, the mineralogy of the clay fraction is important. Of the soil characteristics soil structure provides the most information. Therefore, commonly described soil characteristics can be used with knowledge of operating clogged systems to estimate design values for wastewater infiltration for different soils assuming standard domestic wastewater and design volumes of 570 L d^{-1} per bedroom (150 gpd/bedroom) or greater. A method for predicting loading rates for domestic septic tank effluent based on soil morphological descriptions was developed (Tyler et al., 1991).

In the absence of soil clogging, or in the presence of weakly developed clogging, as is likely when applying wastewaters of reduced organic strength or BOD compared to septic tank effluent, infiltration rates are higher than for clogged soil. The increase in infiltration loading rate for reduced strength wastewater and low BOD wastewater is not uniform or linear, and is much greater for soil with larger pores than for those with fine pores. Therefore, a single factor between loading rates for clogged and unclogged soils cannot be used. For example, sandy soil loading rates are much greater without clogging than for clogged soil while in clayey soils the loading rate difference is small. As with loading rates for clogged soil, loading rates for soil receiving wastewater of low organic strength are related to the pores and therefore the described soil morphology. A method for predicting loading rates for wastewaters of reduced organic strength wastewater based on soil morphological descriptions has been reported (Tyler and Converse, 1994).

Water Percolation and Hydraulic Linear Loading Rate

Once wastewater has infiltrated the soil, it moves without the direct influence of the clogging layer or a non-clogged infiltration surface. Water will move from a zone of higher potential to one of lower. In regions of moderate precipitation and with normal wastewater applications, some water will move downward. In a free draining soil, the added wastewater is not a problem; however, many soils have horizons of slow permeability that restrict downward water movement. If the wastewater application rate along with the natural waters exceeds the permeability of these horizons, episaturation will develop. Dissipation of the episaturation is by vertical movement through the underlying slowly permeable horizons and horizontally downslope beneath the ground surface in the shallow soil horizons. If the water is not dissipated from the zone of episaturation as fast as water is added, the system eventually fails hydraulically.

The maximum horizontal flow per unit length or hydraulic linear loading rate is dependent on the ability of the soil to transmit the water horizontally, the depth of soil for transmission and the slope of the induced surface of groundwater. It is assumed the depth available for transmission is above the restricting horizon and episaturation and below the infiltration surface. This is referred as infiltration distance. The slope is frequently the same slope as the ground surface but this should be estimated during site evaluation. The horizontal flow may be defined using Darcy's Law:

$$F = Kd\frac{dX}{dZ}$$

where F is the wastewater flow horizontally down slope for unit length of infiltration system, K is the horizontal saturated hydraulic conductivity of the soil horizons above the restricting horizon and episaturation, d is the depth of soil for horizontal transmission or the infiltration distance between the infiltration surface and the top of the restricting horizon or episaturation of wastewater down the slope, and dX/dZ is the slope of the groundwater surface often the same as the slope of the ground surface. Sites with deep permeable surface horizons do not have flow restriction and therefore other factors control the hydraulic linear loading rates. For sites with a shallow limiting flow horizon, the steeper the slope, dX/dZ, the greater the linear loading rate. Also, the deeper the shallow permeable horizons or infiltration distance, d, the higher linear loading rate. Sites with the greatest horizontal hydraulic conductivity in the surface horizon will have the greatest hydraulic linear loading rate.

Hydraulic linear loading rates may not be limiting to the design of wastewater infiltration systems, particularly those receiving domestic septic tank effluent. In some cases, the supply of oxygen needed to control soil clogging may be limiting. Supply of oxygen to infiltration systems through soil is discussed in a paper by Erickson and Tyler in this proceedings.

Saturated hydraulic conductivity needed to estimate design hydraulic linear loading rates is related to soil pore sizes and therefore related to field described soil characteristics similar to determining wastewater infiltration or loading rates. The same soil characteristics used to estimate infiltration rates are used as a part of determining hydraulic linear loading rates. The other site characteristics, including the slope and depth of permeable horizons, are also determined during the site evaluation. Since determining final system design is dependent on soil and site characteristics, the site evaluation is the single most important part of the design. If the site evaluation is done incorrectly, the rest of the design will be incorrect.

ESTIMATING HYDRAULIC LOADING RATES

Table 1 is for estimating wastewater infiltration into soil from septic tank effluent (>30 mg L^{-1} BOD) or low organic strength wastewater (<30 mg L^{-1} BOD) and hydraulic linear loading rates based on field described soil and site characteristics of texture, structure, consistence, horizon thickness, and slope. This table was prepared for field practitioners and is presented here as prepared. Therefore, the table contains units in common use. A similar table with metric units could be prepared.

The table is used only for soil horizons of very firm or weaker consistence. Soil horizons of stronger consistence than very firm consistence are not acceptable. Also, the table should not be used for soil horizons with smectitic mineralogy. All characteristics used while determining loading rates are collected by a soil scientist.

To estimate infiltration loading rates for wastewaters of either greater or less than 30 mg L^{-1} BOD or to determine hydraulic linear loading rate, soil characteristics related to infiltration or hydraulic conductivity are needed. Texture, structure, consistence, and mineralogy are most important. Since all design values are estimated from the same soil characteristics, only one table of values is needed. To use the table, the soil must have a consistence of very firm or weaker and clay mineralogy should not be smectitic. If these criteria are acceptable, then texture and structure are used. Abbreviations for soil textures are found in the first column to the left in Table 1. Abbreviations are nationally accepted soil science abbreviations of the

Natural Resource Conservation Service of the United States Department of Agriculture (Schoeneberger et al., 1998). Within the texture row for the horizon of interest, the soil structure of shape and grade are used to select the row containing the infiltration loading rates depending on the BOD of the applied wastewater. Finally in the same row, an array of hydraulic linear loading rates complete the remainder of the row. Since hydraulic linear loading rate is not dependent on the wastewater quality applied, these values are the same regardless of the application infiltration rate. Hydraulic linear loading rate is also related to the slope of the flow surface and the depth of flow. These values are from the site evaluation and are found to the right of the infiltration rate values at top of the table. Ranges of slope and infiltration distance or the thickness of the horizon are along the top. Hydraulic linear loading rate for a horizon is selected with the row identified by the texture and structure. This is done by selecting the slope of the horizontal flow horizon and then the depth of the horizon for horizontal flow. If there is more than one horizon, the contribution to horizontal flow of each horizon is used to determine the hydraulic linear loading rate. If only a portion of a horizon is transmitting water, only the infiltration distance or distance from the infiltration surface to the limiting condition is used.

Values for infiltration hydraulic loading rates and for hydraulic linear loading rates are estimates based primarily on experience. The logic and trends in values presented fit with the scientific basis and with experience. Further research and testing are needed to verify the values. Hydraulic linear loading rates are for domestic wastewater assuming 570 L d^{-1} per bedroom (150 gpd/bedroom). For other wastewater sources, use safety factors similar to those used for domestic wastewater. The design safety factor is imbedded in the design wastewater flow. Designers using actual wastewater flow rates should assume the values in the table for wastewater infiltration are 5 to 10 times higher than should be used when using actual flows.

Assume a site has a 7% slope on the limiting horizon. From the top of the limiting horizon to the bottom of the infiltration is 36 cm (14 inches). The horizon is a silt loam, abbreviation SIL, with weak, abbreviation 1, fine subangular blocky, abbreviation BK, structure that is friable and not smetitic. The infiltration loading rate for a wastewater with BOD >30 mg L^{-1} would be 16 L m^{-2} d^{-1} (0.4 gpd/ft^2) and 24 L m^{-2} d^{-1} (0.6 gpd/ft^2) if the BOD were <30 mg L^{-1}. The hydraulic linear loading rate is 11.4 L m^{-1} d^{-1} (3.0 gpd/ft) regardless of the wastewater type.

For design, there is no need to calculate areas. First determine the linear loading rate from Table 1. From the example above, with a linear loading rate of 11.4 L m^{-1} d^{-1} (3.0 gpd/ft) and a wastewater volume of 1700 L d^{-1} (450 gpd), divide the wastewater volume by the hydraulic linear loading rate to get the length of the system of 46 m (150 feet). The width of a trench is the hydraulic linear loading rate divided by the infiltration hydraulic loading rate. For septic tank effluent and a infiltration hydraulic loading rate of 16 L m^{-2} d^{-1} (0.4 gpd/ft^2), the width of the system would be 2.3 m (7.5 ft.). This width would be acceptable hydraulically but may not account for the oxygen demand.

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	<30 mg/L									
	Shap	Grad			8-12	12-	24-48	8-	12-	24-	8-	12-	24-
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/B K/G	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/B K/G	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/B K/G	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/B K/G	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/B K/G	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/B K/G	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

CONCLUSIONS

The principals of water movement through wastewater infiltration system clogging layers and saturated horizontal flow away from the zone of infiltration can be used to explain the flow of domestic wastewater into and through soil. However, application of principals does not provide working values for design of onsite wastewater treatment systems. Design hydraulic loading rate estimates based on logic and experience for domestic wastewater applications derived from field described soil and site characteristics are in a single table for use by onsite wastewater specialists.

REFERENCES

1. Bouma, J. 1975. Unsaturated flow during soil treatment o septic tank effluent. J. Am. Soc. Civ. Eng. 01(EE6): 967-983.

2. Keys, J.R., E.J.Tyler and J.C. Converse. 1998. Predicting life for wastewater absorption systems. In: D. Sievers (ed.) On-site wastewater treatment. Proc. of the 8th International Symposium on Individual and Small Community Sewage Systems. ASAE. St. Joseph, MI. p. 167-176.

3. Schoeneberger, P.J., D.A. Wysocki, E.C. Benham and W.D. Broderson. 1998. Field book for describing and sampling soils. National Resources Conservation Service, USDA, National Soil Survey Center, Lincoln, NE.

4. Siegrist, R.L. 1987. Hydraulic loading rates for soil absorption systems based on wastewater quality. In: On-site wastewater treatment. Proc. of the 6th National Symposium Individual and Small Community Sewage Systems. ASAE, St. Joseph, MI. p. 232-241.

5. Tyler, E.J. and J.C. Converse. 1984. Soil evaluation and design selection of large or cluster wastewater soil absorption systems. In: On-site wastewater treatment. Proc. of the 4th National Symposium Individual and Small Community Sewage Systems. ASAE, St. Joseph, MI. p. 179-190.

6. Tyler, E.J., E.M. Drozd and J.O. Peterson. 1991. Estimating wastewater loading rates using soil morphological descriptions. In: On-site wastewater treatment. Proc. of the 6th National Symposium Individual and Small Community Sewage Systems. ASAE, St. Joseph, MI. p. 192-200.

7. Tyler, E.J. and J.C. Converse. 1994. Soil acceptance of onsite wastewater as affected by soil morphology and wastewater quality. In: D. Sievers (ed.) On-site wastewater treatment. Proc. of the 8th International Symposium on Individual and Small Community Sewage Systems. ASAE. St. Joseph, MI. p. 185-194.