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## *SMALL SCALE WASTE MANAGEMENT PROJECT*

# Estimating Wastewater Loading Rates Using Soil Morphological Descriptions


by

E. J. Tyler, E. M. Drozd, J. O. Peterson


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# ESTIMATING WASTEWATER LOADING RATES

# USING SOIL MORPHOLOGICAL DESCRIPTIONS

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ABSTRACT

A procedure for establishing design loading rates for subsurface wastewater infiltration systems based solely on field description of soil texture, structure, and consistence is being instituted in Wisconsin. To translate from morphology to loading rates, a sequence of questions is posed. The first question of the sequence with a positive response corresponds to an acceptable predicted loading rate based on treatment and disposal criteria. One group of questions contains criteria which predict soil hydraulic properties unsuited for acceptance of wastewater. The remainder establish design loading rates from 0.8 cm/day (0.2 gpd/ft$^2$) to 3.3 cm/day (0.8 gpd/ft$^2$) based on soil texture and structure.

The procedure has been reviewed by hundreds of field personnel while it was being used for training of soil and site evaluators. The procedures have been through public hearings in Wisconsin as part of the process for inclusion in Administrative Rules. A version of this procedure was included in the Wisconsin Administrative Code July 1, 1991 to replace the percolation test after a three year phase out of the use of the percolation test.

## INTRODUCTION

Infiltration systems are used for the treatment and disposal of the wastewater generated by the facility they serve. Although infiltration systems cannot currently meet all treatment objectives they can meet most and therefore remain a commonly used method of disposal of onsite wastewaters for about one third of the population of Wisconsin. Wastewater infiltration systems will continue to be used for years into the future. Modification for specific pollutant treatment, however, will be needed.

The percolation test is frequently used in the United States to establish design wastewater loading rates. The procedure has met with varying success and is being eliminated in favor of using soil morphology as the basis for establishing loading rates in some states. Some states use soil texture to establish loading rates, while in others soil texture in combination with other soil physical characteristics is used. Still others use some combination of soil morphological description with an interpretation of soil classification or parent material.

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In Wisconsin, a version of the percolation test has been used for each soil and site evaluation except in some sandy soil conditions. For training of soil and site evaluators about the relationships between soil characteristics and water movement in soil, a procedure for estimating design wastewater loading rates based solely upon soil morphological characteristics was developed. The basic system was modified and adopted for general use for establishing design wastewater loading rates in Wisconsin. This paper describes the basis, development, modification and adoption of the procedure for use in the State of Wisconsin.

## BACKGROUND

Criteria for design loading rates for onsite wastewater infiltration systems are established to provide adequate treatment of wastewater and match the long-term infiltration rate. Of particular concern for wastewater treatment are soils with very large continuous pores that allow wastewater to pass rapidly to depths beyond the site evaluation. These soils have very high infiltration rates and hydraulic conductivity. The pores are easy to see and are generally associated with gravelly coarse sand or coarser soil texture. The extreme situation is that of creviced bedrock, which presents very large continuous pores for wastewater to pass. It is a primary task of the site evaluator to predict the treatment capacity of the soil during the site examination.

In other soils that do not have very large continuous pores the long-term acceptance and transmission of the wastewater becomes more critical and sometimes limiting. As wastewater infiltrates the soil, a biological clogging mat develops that acts as a thin film of lower hydraulic conductivity than the underlying soil. The wastewater moves away from the system faster than the wastewater can go though the clogging mat. Therefore, the soil around the wastewater infiltration system is unsaturated. The secondary task of the site evaluator is to predict the unsaturated flow rate or the infiltration of wastewater into the clogging layer. This value is the design loading rate.

Direct measurement of unsaturated flow in the soil is generally difficult, time consuming and expensive (Jaynes and Tyler 1983). The variability of the soil infiltration or hydraulic conductivity is high and therefore many tests are needed to establish significant data. Some of the tests used to measure the unsaturated hydraulic conductivity include the crust test and the instantaneous flow field tests (Bouma et al. 1974). In the laboratory, the one step outflow method has been used (Jaynes and Tyler 1983).

The percolation test does not directly measure the unsaturated flow in the soil. The flow conditions around the test hole have been defined such that the test can be used to determine the average horizontal and vertical components of the saturated conductivity (Elrick and Reynolds 1986). The percolation test can be used to rank soils and has been used to empirically determine a design loading rate for wastewater infiltration systems. As with other field procedures it is time consuming, variable and costly.

Relationships between soil morphological characteristics and wastewater design loading rates or infiltration rates have been reported. Some of these are based primarily on soil texture while others recognize the importance of other morphological characteristics. Work of Hantzche et al. (1982) and Simon and Reneau (1987) demonstrate the use and importance of soil morphological description for estimating wastewater loading rates.

Most soil morphological characteristics described have little direct influence on the soil hydraulic properties. However, many of the factors described are related to the soil porosity and pore size distribution. Soil texture greatly influences the size of the pores around the individual particles. Soil materials of uniform particle size generally have pores sizes in direct proportion to grain sizes. For example, coarse sand soils generally have large pores while clayey soils generally have fine pores. Soil textures composed of both large and small particles may have only fine pores since the fine particles fill the pores created by the large particles. Texture has a very important influence on the soil pore size distribution and therefore on the wastewater flow.

Soil structure creates a secondary set of pores and can greatly affect the pores sizes predicted based on soil texture alone. Single grain and massive soils do not have the secondary pores. The stronger the structure, the better the aggregates or peds are defined and the more pronounced the set of secondary pores in the soil. If the pores created are in the direction of the desired wastewater movement, then the soil structure enhances the wastewater movement; however, if the pores created are perpendicular to the desired wastewater flow, then the structure will be restrictive to flow. Granular, blocky, and prismatic structure generally enhances vertical flow. Platy structure results in reduced vertical flow.

One characteristic of soil consistence is strength. The strength of soil depends in part on the contact of soil particles. Strong soils, defined in the moist condition as "firm" have reduced pores, have close contact of soil particles and therefore have high bulk density and reduced porosity. Soils of high strength generally have low infiltration rates and low hydraulic conductivity.

Soil with high amounts of smectite clay minerals may also have low infiltration rates and hydraulic conductivity. The expansive clays swell on wetting and close the larger pores in the soil system. Since wastewater infiltration systems are always wet the clays remain swelled and would be expected to have reduced hydraulic conductivity. Soil characteristics used to predict low wastewater infiltration rates are associated with high smectite clay contents. Therefore the system may predict the proper loading rates but the system does not account directly for soils of high smectite clay content.

## BASIS FOR PROCEDURES

The primary objective of the soil descriptive system is to recognize soils and soil conditions that will not offer adequate treatment of wastewater. Generally soils with the lowest conductivity that still will accept the wastewater as well as the precipitation would be the best soil. Soils that have high conductivity may not provide the retention time needed for treatment while wastewater is transmitted to the groundwater. Also, soils that cannot accept the wastewater and the precipitation may result in surfacing of wastewater and create a threat to health and surface water quality.

The system devised should recognize those soils that offer at least a minimum level of treatment and estimate wastewater loading rates on mineral soils that do not contain appreciable contents of smectite or swelling clay minerals. The wastewater loading rate estimate is determined for the soil horizon depth directly below the proposed system bottom; however, consideration must be given for deeper horizons which may have a lower loading rate. Also, the description should use a common language, be simple and direct and be consistent among users. In summary, the system is to:

1. Account for the treatment capability of the soil for transmitted wastewater,

2. Recognize those soils that cannot accept the combined precipitation and wastewater loading,

3. Correctly estimate a long term infiltration rate for a wastewater infiltration system for the horizon of system installation in soils believed to provide adequate treatment and meet minimum hydraulic needs,

4. Must use an accepted nomenclature that can be used by soil scientists and others familiar with the common nationally used soil science terms,

5. Be simple and direct providing interpretations of design loading rate directly from the morphological description without intermediate interpretations of parent materials or soil taxonomic name,

6. Be consistent among users, such that, once the morphology is described the procedure will lead to the same loading rate for each user.

## DEVELOPMENT HISTORY

While searching for a teaching method to relate standard soil descriptive methods to determine design loading rates, a sequence of events occurred. The development process included input from the participants of the training, which allowed the experience of many field personnel to be included. Also, having many involved with the development of the system increased the possibility of acceptance. However, inclusion in State Administrative Code was not intended when the system was developed.

The Guide to Estimating Vertical Saturated Hydraulic Conductivity of the USDA Soil Conservation Service (Soil Survey Staff 1983) was initially used as the basis of the system. Along with the values of saturated flow of the Soil Conservation Service, unsaturated hydraulic conductivities were provided that would likely match the loading of the subsurface wastewater infiltration systems. The guide met many of the criteria needed for a system to relate morphology to loading rate. Recognizing that unsaturated flow would not depend upon the large pores in the soil, description of vertical cracks was eliminated from the system. The system began by recognizing the soils of limited treatment capability and then proceeded with a series of statements about soil morphology beginning with the highest loading rate and progressing to the lowest. Table 1 is a version of the table developed for teaching to estimate loading rates with the modified system of the Soil Conservation Service.

The system presented in Table 1, while useful for teaching, was somewhat cumbersome. It does present the rapidly permeable soil first and therefore recognizes the treatment objective. However, the slowly permeable soil condition which also can lead to minimum treatment is recognized at the end of the system.

Based on the logic in Table 1 and using some of the teaching experiences, a computer-based procedure with a series of questions concerning soil morphology related to estimated loading was developed. The first teaching version was used with a group of 100 soil evaluators. The group offered many suggestions and modifications were made. The result of this group interaction was a modified scheme. Table 2 is the series of questions developed and latter modified with the group input.

This second version offered a direct and simple method to teach about the relation between the morphology description and the objectives for the system. The sequence of questions guides the user from the sites that

Table 1. Design Loading Rates for Various Soil Morphological Conditions

| Soil morphological condition[a] | Design loading rate |
|---|---|
| | ($gpd/ft^2$) |
| Gravelly coarse sand and coarser. | Not recommended |
| Coarse sand but not cemented. | 1.10 |
| Medium sand with single grain structure and loose to friable consistence but not cemented. | 0.9 |
| Other sands and loamy sands with single grain or weak structure but not of extremely firm or cemented consistence; sandy loams, loams and silt loams with moderate or strong structure except platy and loose to friable consistence. | 0.6 |
| Sandy clay loams, clay loams and silty clay loams with weak structure but not massive and not of firm or cemented consistence; some sandy clays, clays and silty clays with moderate and strong structure but not platy and not of firm or cemented consistence. | 0.25 |
| Other soils of high clay content with weak or massive structure, extremely firm or cemented consistence. | Not recommended |

[a] Descriptions are estimates and assume that the soil does have appreciable amounts of swelling clays. Soils with platy structure, compacted or high density should be used with care or avoided.

would offer low potential for wastewater treatment because of rapid transport to those offering minimum treatment because of low acceptance and finely to the loading rates for other soils. As with the first version, only defined and accepted soil morphological descriptive terms are used and no interpretations of soil genesis or taxonomy are required. Loading rates with this version are lower than for the first version but seemed to fit the experience of the site evaluators in Wisconsin. Other areas may find that the loading rates should be different.

After using the guide for teaching there was interest in using the procedure to estimate wastewater loading rates and to eliminate the use of the percolation test. Public and private groups worked intensively with the basic system and within a short time made a proposal to the State Department of Industry, Labor, and Human Relations, which regulates onsite wastewater disposal in Wisconsin. Since many felt that the guide used for teaching did not offer the design options that might be used to meet the treatment and hydraulic goals, such options as sand blankets were included as footnotes. Therefore, rapidly permeable soils could continue to be used for onsite wastewater disposal. The Wisconsin Administrative Code which incorporated the basic version with suggestions from user groups is presented in Table 3.

Table 3 considers differences in design between beds and trenches. The final version used in code carries seven footnotes that contain significant design options. Some of these options were not previously in the administrative rules because Wisconsin allowed wastewater infiltration systems on very permeable sites. The basic principles used in the educational

Table 2. Estimating Wastewater Infiltration Rates

| Soil horizon characteristics | Loading ($gpd/ft^2$) |
|---|---|
| A. Is the texture gravelly coarse sand or coarser? | 0.0 |
| B. Is the structure moderate or strong platy? | 0.0 |
| C. Is the texture sandy clay loam, silty clay loam or finer, with weak platy structure? | 0.0 |
| D. Is the consistence stronger than firm (moist) or hard (dry), or any cemented class? | 0.0 |
| E. Is the texture sandy clay, clay or silty clay of high clay content, with massive or weak structure, or silt loam with massive structure? | 0.0 |
| F. Is the texture sandy clay loam, clay or silty clay loam with massive structure? | 0.0 |
| G. Is the texture sandy clay, clay or silty clay of low clay content, with moderate or strong structure? | 0.2 |
| H. Is the texture sandy clay loam, clay loam or silty clay loam, with weak structure? | 0.2 |
| I. Is the texture sandy clay loam, clay loam or silty clay loam, with moderate or strong structure? | 0.4 |
| J. Is the texture sandy loam, loam or silt loam, with weak structure? | 0.4 |
| K. Is the texture sandy loam, loam or silt loam, with moderate or strong structure? | 0.6 |
| L. Is the texture fine sand, very fine sand, loamy fine sand or loamy very fine sand? | 0.6 |
| M. Is the texture coarse sand, sand loamy sand or loamy coarse sand with single grain structure? | 0.8 |

programs remain in the code version. A modified version is being used for establishing loading rates for Wisconsin at-grade and mound wastewater infiltration systems (Converse and Tyler 1990; Converse et al. 1990).

The first major version had five different loading rates from 0.0 to 1.1 $gpd/ft^2$ (Table 4). The second had a loading rate range from 0.0 to 0.8 $gpd/ft^2$ and also had five loading rates. The code version also has a loading rate range of 0.0 to 0.8; however, there are eight loading rate options.

Table 3. Maximum Wastewater Infiltration Rates for Design of Soil Absorption Systems (Wisconsin Administrative Code 1991)

If the answer to the condition is yes, the infiltration, exposed natural soil surface for the system shall be sized using the identified soil loading factor in gallons per square foot per day.[a,b,c]

| Soil condition | Beds | Trenches |
|---|---|---|
| A. Is the soil texture of the entire profile 3 feet below the infiltrative surface extremely gravelly sand, gravelly coarse sand or coarser? | 0.4[d] | 0.4[d] |
| B. Is the soil structure of the horizon moderate or strong platy? | NP[e,f] | 0.2[g] |
| C. Is the soil texture of the horizon sandy clay loam, clay loam, silty clay loam, silt loam or finer, and the soil structure weak platy? | NP[e,f] | 0.3[g] |
| D. Is the moist soil consistence of the horizon stronger than firm or any cemented class? | NP[e,f] | NP[e,f] |
| E. Is the soil texture of the horizon sandy clay, clay or silty clay of high clay content, and the soil structure massive or weak? | NP[e,f] | NP[e,f] |
| F. Is the soil texture of the horizon sandy clay loam, clay loam, silty clay loam, silt or silt loam and the soil structure massive? | NP[e,f] | 0.2[g] |
| G. Is the soil texture of the horizon sandy clay, clay or silty clay of low clay content, and the soil structure moderate or strong? | 0.2 | 0.3 |
| H. Is the soil texture of the horizon sandy clay loam, clay loam, silty clay loam or silt loam and the soil structure weak? | 0.2 | 0.3 |
| I. Is the soil texture of the horizon sandy clay loam, clay loam or silty clay loam, and the soil structure moderate or strong? | 0.4 | 0.5 |
| J. Is the soil texture of the horizon loam or sandy loam and the soil structure massive? | 0.3 | 0.4 |
| K. Is the soil texture of the horizon loam or sandy loam and the soil structure weak? | 0.4 | 0.5 |
| L. Is the soil texture of the horizon sandy loam, loam or silt loam, and the soil structure moderate or strong? | 0.5 | 0.6 |
| M. Is the soil texture of the horizon very fine sand or loamy very fine sand? Or condition N below but with massive soil structure? | 0.4 | 0.5 |
| N. Is the soil texture of the horizon fine sand or loamy find sand? | 0.5 | 0.6 |
| O. Is the soil texture of the horizon loamy sand, sand or coarse sand? | 0.7 | 0.8 |

Table 3. Footnotes

[a] The infiltration rates may be adjusted due to crossing horizons at the proposed infiltrative surface. Where such conditions occur, a weighted average may be used to determine the infiltratin rate.

[b] The infiltration rates and soil conditions specified may be verified by the county or department, who may require modification of these rates, particularly where soil conditions exist that are not specifically referenced in this table.

[c] A soil description report shall be completed for each soil profile. The reported texture, structure, and consistence shall be used in calculating the loading rate of the infiltrative surface.

[d] Pressure distribution shall be provided except that doses shall be provided more than four times per day to increase retention time. Department written approval is required for sites where voids between gravels and cobbles are not filled with soil material of 2 mm or less in size. If at least a 6-foot separation below the proposed system to a limiting factor is evaluated and determined, or if a sand textured blanket at least 1 foot thick is provided at the infiltrative surface, then a soil loading rate of 0.8 may be used with or without pressure distribution. Split spoon or power auger equipment may be used for evaluations at depth of more than 3 feet below the proposed system, provided such usage is noted on the soil description report.

[e] NP = not permitted. Systems may be permitted in these soils only with prior department approval. Site-specific department approval will not be required where standard approvals have been issued based on a design concept or regional soil conditions.

[f] Soil horizons meeting conditions D or E are not permitted within 3 feet below the infiltrative surface for either seepage beds or trenches. Soil horizons meeting conditions B, C, or F are not permitted within 3 feet below the infiltrative surface for seepage beds.

[g] Pressure distribution is required.

Table 4. Comparison of the Loading Rate Guide Approximations

| Version | Loading range | Number rates |
|---|---|---|
| 1 | 0 to 1.1 | 5 |
| 2 | 0 to 0.8 | 5 |
| Code | 0 to 0.8 | 8 |

## USE OF THE GUIDE

As part of the final adoption and use of the procedure, training and certification of Wisconsin Certified Soil Testers were required. Seven contact hours including classroom review of the Soil Conservation Procedures followed by practice describing soils in the field was provided. The training was first offered 1.5 years before the code change was made throughout the state in a cooperative effort between the University of Wisconsin System, the State Department of Industry, Labor, and Human Relations, the Small Scale Waste Management Project, and Wisconsin counties.

At the conclusion of the training, a two-part evaluation exam was given, which included a field profile description, estimation of loading rates based on the soil description, and a ten-question, multiple-choice exam on the principles of soil description. Those satisfactorily completing both exam portions are certified to estimate loading rates without running the percolation test. The percolation test will be phased out by 1994.

## CONCLUSIONS

The soil description system replaces the percolation test as a procedure for establishing wastewater infiltration rates. The procedure provides reasonable loading rates with reduced rates on the coarser soils. The final system blends design changes with the soil properties to enhance wastewater treatment. The procedure for developing the guide and incorporating it into Wisconsin Administrative Code demonstrates the participatory approach to code change.

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