Soil suitability for on-site sewage treatment in the Flathead Valley, Montana : soil permeability, variability, and ground-water contamination

by Bruce John Bauman

A thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Crop and Soil Science
Montana State University

Abstract:
A field study of in situ soil hydraulic conductivity was conducted in the Flathead Valley of northwestern Montana. Of special interest was interpretation of soil properties in terms of suitability for on-site sewage treatment systems. Thirteen sites were selected, soil profiles described and sampled, and the gypsum crust method used to determine hydraulic conductivity at saturation and in the near-saturation range. Multivariate statistical techniques were employed for data analysis.

Results suggest that soil water movement is strongly influenced by the vertical variability (textural stratification) often noted in soil profiles in the study area. Complex glacial and proglacial depositional environments are responsible for this variability, which is. also strongly expressed horizontally as lateral variation across the landscape. Soils formed from similar parent materials (and/or with similar textural properties) generally exhibit similar hydraulic characteristics in the saturated and near-saturated range. Substantial variability within these groups is not uncommon. This variability requires that determination of site/soil suitability for septic systems include on-site observations of soil profile characteristics. The implications of textural stratification within the soil profile need to be considered for proper design and long-term operation of individual on-site sewage treatment systems. Multivariate statistical techniques were employed in analysis of the physical and chemical properties of the soil horizons studied. Principle component analysis was shown to be an effective tool for graphical expression of soil profile variability. Cluster analysis demonstrated the ability of such methods to group horizons with similar properties.

Aquifer assessment should be included as an integral component of the site evaluation process for on-site sewage treatment systems. A simple model has been proposed that is designed to assist local regulatory officials in their efforts to minimize the environmental impacts of sewage treatment from suburban and rural housing developments. The model demonstrates that it is important to estimate the nitrogen load to the receiving aquifer (including the potential for denitrification), evaluate the diluting capacity of the aquifer* and also assess the relative importance of the particular ground-water system.

SOIL SUITABILITY FOR ON-SITE SEWAGE TREATMENT IN THE FLATHEAD VALLEY, MONTANA: SOIL PERMEABILITY, VARIABILITY, AND GROUND-WATER CONTAMINATION

by

BRUCE JOHN BAUMAN

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Doctor of Philosophy

in

Crop and Soil Science

MONTANA STATE UNIVERSITY
Bozeman, Montana

March 1985

APPROVAL

of a thesis submitted by

Bruce John Bauman

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for admission to the College of Graduate Studies.

March 15, 1985
Date

William N. Scheff Jr.
Chairperson, Graduate Committee

Approved for the Major Department

March 26, 1985
Date

Dwane G. Miller
Head, Major Department

Approved for the College of Graduate Studies

3-27-85
Date

M P Malone
Graduate Dean

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a doctoral degree at Montana State University, I agree that the Library shall make it available to borrowers under rules of the Library. I further agree that copying of this thesis is allowable only for scholarly purposes, consistent with "fair use" as prescribed in the U.S. Copyright Law. Requests for extensive copying or reproduction of this thesis should be referred to University Microfilms International, 300 North Zeeb Road, Ann Arbor, Michigan 48106, to whom I have granted "the exclusive right to reproduce and distribute copies of the dissertation in and from microfilm and the right to reproduce and distribute by abstract in any format."

Signature Bruce J. Bauman

Date March 20, 1985

ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation to Dr. W.M. Schafer for his generosity, guidance, suggestions, and friendship during the period I have spent completing my doctoral degree.

I would also like to gratefully acknowledge the contributions of the members of my graduate committee, Drs. S.G. Custer, A.H. Ferguson, C. Montagne, and R.A. Olsen, to the development of this thesis.

The financial assistance of the Flathead River Basin Environmental Impact Study in supporting my graduate studies and research is deeply appreciated, as well as support from the Department of Plant and Soil Science.

My parents, Mrs. Vera Bauman and the late Walter R. Bauman are deserving of praise for their continued encouragement during the pursuit of my professional goals. The spiritual support provided by the memory of my late parents-in-law, Elinore E. and Robert M. Bair also deserves acknowledgement.

A very special and deep expression of love and gratitude is due my loving wife, Emily Elinore Bair, whose unremitting love and friendship has provided a source of physical and spiritual nourishment throughout my graduate studies.

TABLE OF CONTENTS

TABLE OF CONTENTS-Continued

LIST OF TABLES

Tables Page

LIST OF FIGURES

Figures Page

Figures Page

ABSTRACT

A field study of *in situ* soil hydraulic conductivity was conducted in the Flathead Valley of northwestern Montana. Of special interest was interpretation of soil properties in terms of suitability for on-site sewage treatment systems. Thirteen sites were selected, soil profiles described and sampled, and the gypsum crust method used to determine hydraulic conductivity at saturation and in the near-saturation range. Multivariate statistical techniques were employed for data analysis.

Results suggest that soil water movement is strongly influenced by the vertical variability (textural stratification) often noted in soil profiles in the study area. Complex glacial and proglacial depositional environments are responsible for this variability, which is also strongly expressed horizontally as lateral variation across the landscape. Soils formed from similar parent materials (and/or with similar textural properties) generally exhibit similar hydraulic characteristics in the saturated and near-saturated range. Substantial variability within these groups is not uncommon. This variability requires that determination of site/soil suitability for septic systems include on-site observations of soil profile characteristics. The implications of textural stratification within the soil profile need to be considered for proper design and long-term operation of individual on-site sewage treatment systems. Multivariate statistical techniques were employed in analysis of the physical and chemical properties of the soil horizons studied. Principle component analysis was shown to be an effective tool for graphical expression of soil profile variability. Cluster analysis demonstrated the ability of such methods to group horizons with similar properties.

Aquifer assessment should be included as an integral component of the site evaluation process for on-site sewage treatment systems. A simple model has been proposed that is designed to assist local regulatory officials in their efforts to minimize the environmental impacts of sewage treatment from suburban and rural housing developments. The model demonstrates that it is important to estimate the nitrogen load to the receiving aquifer (including the potential for denitrification), evaluate the diluting capacity of the aquifer, and also assess the relative importance of the particular ground-water system.

INTRODUCTION

Many Americans are attracted to the amenities provided by low-density housing developments in suburban and rural locales. Through the early part of this century, high-density development was the rule, but with the advent of modern transportation systems, rural electrification, and steadily rising disposable income, millions of families have taken up residence in non-urban, low-density developments. This segment of the population of the United States has been growing rapidly. Extension of municipal sewerage to such low-density housing areas is economically prohibitive, necessitating the use of on-site soil treatment methods for the purification and disposal of sewage (U.S. Environmental Protection Agency, 1977). As the number of households employing on-site methods of sewage treatment has increased over the years, concerns have been raised regarding the potential for pollution of both surface and ground-water sources (Woodward et al., 1961).

Generally, the national housing trends outlined above hold true for Montana (U.S. Census Bureau figures for increases in the number of septic systems in Montana counties for the period 1960-1980 are contained in Appendix 1). Specifically, a notable example is the Flathead Valley area in northwestern Montana, which has experienced rapid development in the last 15 years. In this area almost half of all homes employ septic systems as their means of wastewater treatment

(U.S. Bureau of the Census, 1980). Previous to the work described in this report, there has been no scientific examination of the soil properties of this region in relation to hydraulic conductivity and septic system operation.

The primary focus of this study was to evaluate the physical and chemical properties of a variety of soil series in the Flathead Valley, obtain some specific in situ hydraulic conductivity data (saturated and unsaturated flow), and analyze this information in terms of septic system performance. The vastness and variability of the geographical area preclude a comprehensive, basin-wide characterization of soil water movement. However, this study does establish a data base of hydraulic conductivity values in this region of the state.

An underlying goal of this study was to employ multivariate statistical techniques to examine the similarities and differences between sites and horizons. Such methods as principle component analysis, cluster analysis, and discriminant analysis have been widely used as classification tools in the earth sciences, but have only rarely been used to analyze and classify data from soil profiles. The intent was to evaluate their utility in distinguishing groups of soil horizons.

In the past decade there has been increasing concern regarding the environmental consequences of septic sytems, especially in terms of their impact on ground-water quality. This problem is also addressed in this thesis through an examination of the interactions of septic systems, soils, and ground water. The findings of a number of research studies concerning soil treatment of septic tank effluent and ground-water nitrate contamination from septic systems have been evaluated. This information is used to develop a simple model that illustrates relative impact of different environmental parameters on resultant nitrate concentration of ground water. This discussion also demonstrates the importance of aquifer assessment as an integral part of the site evaluation process, and provides a list of factors to be considered for aquifer assessment.

During research into these topics, much was learned about the status of on-site sewage treatment systems in Montana. Summary information concerning the increase of septic systems in Montana counties over the last 20 years is presented in Appendix 1, along with a discussion of regulation of this form of sewage treatment, and suggestions for improvement in state regulation.

SOIL PERMEABILITY, VARIABILITY, AND SEPTIC SYSTEMS IN THE FLATHEAD VALLEY, MONTANA

INTRODUCTION

The typical on-site waste treatment method used in the United States is the septic system, consisting of a septic tank and soil absorption field. The tank serves as a settling basin, providing primary wastewater treatment. Effluent from the tank flows to the soil absorption field, where secondary treatment occurs as the effluent percolates through the soil and geologic strata to the water table (Figure 1). Several soil properties play important roles in determining the efficiency of treatment of septic system effluent. Perhaps the most important is hydraulic conductivity, the rate of water movement through the soil. Accurate assessment of the hydraulic properties of the soil is necessary for proper septic system design. Improper design increases the likelihood of system failure, potentially causing contamination of surface and ground-waters (Bouma, 1971).

In the spring of 1981, a field study was initiated in the Flathead Valley of northwestern Montana, whose focus was to characterize the physical, chemical, and hydraulic properties of a variety of soil series in the area. This information was to be interpreted in terms of suitability of these soils for on-site sewage treatment systems. The use of multivariate statistical analyses as a tool for interpretation of soil profile data was also investigated with this data set.

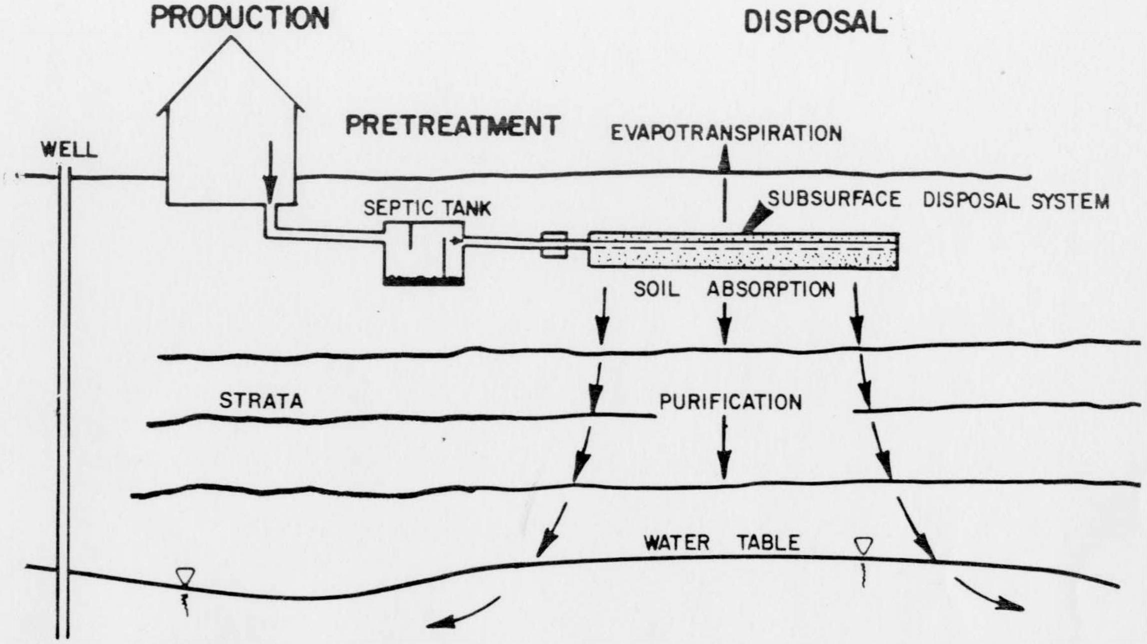

Figure 1. Soil treatment of wastewater by a typical septic system. (after U.S. Environmental Protection Agency, 1978).

LITERATURE REVIEW

Site Evaluation for On-Site Sewage Treatment

Soil Properties

The suitability of any particular parcel of land for on-site wastewater treatment is largely controlled by the physical properties of the soil at that location (Tyler et al., 1977). Successful operation of septic systems requires that two conditions must be fulfilled. First, the liquid effluent must move through the soil at a rate slow enough for it to be properly treated. Second, the soil must be capable of accepting the effluent at a rate that is greater than that at which it is produced by the household. If either of these two conditions are not met, the system is said to have failed. A failure of the first type is called a 'treatment' failure, and of the latter, an 'hydraulic' failure (U.S. Environmental Protection Agency, 1978).

Design criteria for determining the capability of an individual soil to properly accept and treat effluent are based both on external and internal properties of the soil (Baker, 1978). External factors have been well defined for a number of years, and have been incorporated into the standard procedures for determing site suitability. They include: depth to bedrock; depth to the seasonal water table; surface slope; and susceptibility to flooding (U.S. Public Health Service, 1967). While different states have required different criteria for these factors, general limitations are: 1) a minimum of one meter (three feet) between the bottom of the drainfield trench and ground water or bedrock; 2) maximum allowable slopes of 15-25 percent; 3) no sites permissible in floodplains (Parker et al., 1977).

Another important external factor is the relationship of the proposed drainfield site to the local surface hydrology. Sites on concave slopes or below slopes of poor permeability will receive additional water during precipitation and runoff events. This is especially true during periods (e.g. early spring) when the soil surrounding the frost-free drainfield may still be frozen (Mellon, 1967). Runoff of this nature increases the total hydraulic load the drainfield area would receive, potentially causing intermittent failures, and may lead to permanent hydraulic failure (Anderson, 1981).

Internal factors which influence site suitability for septic systems are those characteristics and properties of the soil that influence its ability to transmit water through its profile (i.e. the permeability or hydraulic conductivity of the soil). Morphological attributes of the soil that should be considered include: 1) soil texture or particle size distribution; 2) soil structure; 3) bulk density; 4) porosity; 5) pore size distribution; 6) stratification of different soil textures within the profile (Bouma, 1973; Anderson, 1977; Parker et al., 1977).

Soil texture, structure, and bulk density are characteristics that determine the porosity and pore size distribution of the soil matrix. Soils with higher fractions of silt and clay-sized particles will generally have lower permeabilities than soils containing abundant sand. Similarly, well-developed soil structure and low bulk densities generally result in higher porosity and large numbers of larger pores, promoting faster movement of water through the soil (Horn, 1971).

Textural stratification influences water movement in that both a coarser soil layer underlying a finer textured layer, or a fine-textured soil horizon below a coarser horizon, will retard the downward flow of water to varying degrees. In the former case (e.g. silt loam over sand), the matric tension of the sand material is initially not great enough to attract the water held relatively tightly by the silt loam soil above. Gradually, as water content increases in the fine-textured layer, matric tension will drop sufficiently to allow movement between layers (Miller, 1969). In the latter case, it is simply the lower hydraulic conductivity of the underlying horizon that inhibits water movement. Both types of stratification will result in decreased flow from a septic system drainfield.

In addition to these physical properties, soil morphological characteristics are used to evaluate site suitability for septic systems. Soil color patterns (mottles) and general soil color have been used as indicators of the general year-long moisture regime of a soil (Simonson and Boersma, 1972). Brighter, reddish colors suggest a well-drained soil that allows water to move through it freely. Dull, gray colors are indicative of poorly-drained soils that remain in a near-saturated condition for long periods of time (Soil Survey Staff, 1960). Septic systems installed in poorly-drained soils may be subject to premature hydraulic failure, and/or provide inadequate treatment of effluent (Wisconsin Bureau of Environmental Health, 1979).

The presence of mottles in a soil profile has also been used as an indicator of the upper boundary of a seasonal water table (Simonson and Boersma, 1972). As noted earlier, most states require that at least one meter (three feet) of separation between the bottom of the drainfield trench and the seasonal maximum high water table. However other researchers have found that mottles do not always occur in soils that are subject to saturation for even extended periods of time (Vepraskas and Wilding, 1983; Franzmeier et al., 1983; Pickering and Veneman, 1984), and sometimes they occur in soils that do not experience saturated conditions (Fredrickson, 1980).

Measurement of Hydraulic Characteristics

While there are many factors which influence site suitability for septic systems, traditionally the most important has been soil permeability as determined by the percolation test (Anderson et al., 1977). The results of this test have been used to determine both site suitability and the size of the drainfield required for the projected wastewater flow. The use of the percolation test (perc test) as a predictive tool for site suitability has its roots in the work performed by Henry Ryon in 1929. He developed a curve (later converted to tabular form) which used the perc test to determine the rate at which effluent should be applied to the soil (McGauhey and Krone, 1967). The relationships defined by Ryan were adopted by many public health officials and over a period of time became the standard for determining both the suitability of a site of waste disposal and for determining the size of the drainfield needed.

Slightly modified by subsequent research, the perc test has remained the most widely used tool for sizing septic tank drainfields throughout the U.S. This in spite of the fact that it has been widely critized by many researchers in the field of on-site waste disposal (Winneberger, 1967; Bouma, 1971; Anderson, 1973; Healy, 1973; Baker, 1977; U.S. Environmental Protection Agency, 1978). The focus of most of the criticism of the test is that results are inherently variable, and that it tends to underestimate the absorption field area required for some soils (especially coarse-textured soils with high perc rates).

Winneberger (1967) found that a series of percolation tests performed within a small area of uniform soil yielded perc rates varying from 9-33 minutes/cm (23-83 minutes/inch). In a study of 1500 perc tests on 250 Pennsylvania soils, Derr et al. (1969) reported an average coefficient of variation (CV = standard deviation/average) for the 4-8 tests performed at each site was 73 percent. Over 20 percent of the sites had a CV greater than 100 percent. Data from Bouma (1971) for six Wisconsin soils showed and average CV of 50 percent, and Barbarick et al. (1976) found a range of 7-48 percent for nine Arizona soils.

While this range of values demonstrates the variability of data obtained from the perc test, such values probably represent as accurate a determination as can be made with this method. In each case the perc test was conducted by scientists attempting to minimize any variation in procedure between successive tests. It has been argued that such care is rarely taken by those who routinely perform perc tests (Winneberger, 1974). Winneberger (1974) reported the results of a study in which fieldmen (employees who regularly performed perc tests) from three engineering firms were asked to perform perc tests at each of nine locations on a single 1/4 acre lot. The range in rates obtained in this experiment for all tests over the entire lot was 1-100 minutes/cm (2-259 minutes/inch), and for any one of the nine locations on the lot, 1.2-90 minutes/cm (3-229 minutes/inch). Allowing for some inherent error due to soil variability, he concluded that the values obtained from perc tests depended more on the procedures of the particular fieldman than on soil characteristics. Potential sources of variability in the perc test have been shown to be hole diameter and geometry, length of presoak period, amount of hydraulic head during the testing period, and soil anisotropy and heterogeneity (Healy and Laak, 1973; Barbarick, 1976).

Further criticism of the perc test comes from those who state that it is a measure of saturated flow through soil, while it is the process of unsaturated flow that actually occurs under mature septic tank drainfields. A study by the U.S. Public Health Service (1950) revealed that the equilibrium loading rate (the amount of effluent actually percolating into the soil) under the drainfields evaluated represented a 98 percent reduction in the flow rate compared to the saturated flow rate determined by the perc test. The study suggested that some sort of barrier to flow had developed in the soil.

Further research by Thomas et al. (1966), and McGauhey and Krone (1967), demonstrated that a hydraulically resistant layer forms at the bottom of the drainfield trench. Years earlier, (Allison, 1947) had shown in a laboratory study that soils kept saturated for extended periods of time developed a clogging zone at the infiltrative surface that was formed from the by-products of anaerobic bacterial activities. Other researchers (Jones and Taylor, 1965; de Vries, 1972; Kristiansen, 1981) have reported similar results. This clogging zone (also referred to as a mat, biomat, or crust) is a complex mixture of micro-organisms, the by-products of their metabolic processes (primarily polysaccharides, which adhere to the soil particles), and other organic matter from suspended solids filtered out of the septic tank effluent. The result of the formation of this biomat is a reduction in the effective porosity (and thus the permeability) of the soil infiltrative surface. This creates a limiting barrier to infiltration, reducing effluent flow from the drainfield trench. Importantly, it also creates conditions of unsaturated flow in the soil beneath the absorption field (Bouma et al., 1972).

Bouma et al. (1972) determined that such a mat usually develops during the first year of operation of a drainfield. Organic matter continues to accumulate and further reduce infiltration until an equilibrium situation is reached, where the rate of crust formation at the anaerobic soil infiltrative surface is matched by the rate of destruction in the aerobic zone several centimeters below the bottom of the drainfield trench. In an extensive evaluation of septic system operation in Wisconsin (Bouma et al., 1972), measurements were made of soil matric tensions existing under drainfields with clogging mats. Tensions were found to be in the range of 20 to 100 cm water, indicating unsaturated conditions in the soil below the mat.