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A Computer-Assisted Approach For Preparing
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Marc Jay Rogoff

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Major professor

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A COMPUTER-ASSISTED APPROACH FOR PREPARING RATINGS OF SOIL POTENTIAL FOR URBAN LAND USE MANAGEMENT

By

Marc Jay Rogoff

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ABSTRACT

A COMPUTER-ASSISTED APPROACH FOR PREPARING RATINGS OF SOIL POTENTIAL FOR URBAN LAND USE MANAGEMENT

By

Marc Jay Rogoff

For more than 15 years soil interpretations have followed a general procedure of rating soils by limitations. Yet, these ratings do not necessarily indicate suitability since some limiting soil properties may not absolutely restrict certain land uses. It has been very common for a community to survey its soils only to find that almost all soils have severe limitations for different land uses. Rather than pointing out problems, emphasis in soil interpretations should be shifted to a more rewarding discussion of feasible alternatives and their costs for best achieving development potential. Soils within a given area could then be arranged according to their potential for a particular use, with statements as to what designs are needed to overcome the limitations, and the continuing problems after treatment.

This study was concerned with developing a set of techniques which would help prepare soil potential ratings for urban land uses and communicate these interpretations to soil survey users. The

techniques developed were illustrated by a test conducted in Windsor Township, Eaton County, Michigan. A systematic procedure was employed to numerically rate a soil's potential for the following land uses: (1) septic tank filter fields for on-site waste disposal; (2) residential roads and streets; (3) residential dwellings with basements; (4) residential dwellings without basements; and (5) excavations for residential waterlines.

A thorough investigation of the literature was undertaken to identify construction designs and development costs needed to overcome soil limitations for these five land uses. Construction trade organizations, individual contractors, and state, and local governmental agencies were contacted to obtain this information.

Estimates were made of continuing limitations remaining after devices have been installed to correct soil hazards. A three-class system, employing the terms, "slight," "moderate," and "severe," was used to indicate the severity of these continuing limitations. The rating of a given soil in such a system signified the degree to which soil hazards have been corrected or overcome by special designs or treatments, and a prediction of the cost and level of maintenance required for their upkeep.

Data collected were entered into an existing natural resource inventory for Windsor Township which contained a soils and land use data bank assembled using a 10-acre dot grid. A computer software system, RAP (Resource Analysis Package), was used to assist in the retrieval, manipulation, and analysis of this spatially-encoded data.

Soil potential ratings for the land uses were generated with the aid of a multi-dimensional scaling program. Soil potential for a specific land use was defined as a function of the costs of construction practices required to overcome soil limitations and the continuing limitations remaining after treatment. The resulting soil potential index values (ranging from 0 to 100) were used to assign each soil to one of four qualitative classes of soil potential employing the terms, "excellent," "good," "fair," and "poor." A computer grouping program was used to select statistically optimal class intervals for grouping the soils into the rating classes. A computer mapping program available in RAP helped draw interpretive maps illustrating soil potentials and limitations for each of the land uses.

Results indicated that by applying different corrective measures to soils with severe limitations, the amount of suitable land for these uses may potentially be increased in Windsor Township. Land which may have been unsuitable for urban development may now be available, provided that certain corrective measures are applied to overcome soil hazards. Thus, urban growth can take place in large areas for which development has not previously been planned. The introduction of new innovative technologies to overcome these soil hazards invites serious questions regarding the impact on a region's land use regulations.

To my father and the memory of my mother.

ACKNOWLEDGMENTS

Many people have provided encouragement and assistance in the development and completion of this study. To all these people I extend my deepest gratitude.

The author wishes to express his sincere appreciation to his major professor and dissertation director, Dr. Eckhart Dersch, Professor of Resource Development, for his friendship, guidance, and direction during the entire term of this author's doctoral program.

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Appreciation is extended to the many construction trade organizations and local contractors in the Lansing area who offered critical help and assistance during the study. The author would like to thank the personnel of the U.S. Soil Conservation Service, especially Dr. Donald McCormack and Dr. David Slusher, for their encouragement and suggestions during the research and writing of this document.

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CHAPTER I

INTRODUCTION

Introduction to the Problem

Historically, land in the United States was considered a free good and open to all those willing to devote their labor and skills to clear and work it. Government land policies encouraged disposal of a bulk of the public domain, especially favoring fee-simple ownership of this free or cheap land. Nearly everywhere settlers believed they were faced with virtually limitless areas of rich grasslands and took the soils on which they based their life dreams for granted. More often than not, luck played a large part in whether they found good soil or poor soil. By the 1890's many farms in the west which were located on poor or marginal soils had failed miserably after only a few short years of prosperity.

These mistakes made by the early settlers stimulated a greater awareness of the need to look at soil resources themselves. In 1894 a Division of Agricultural Soils was initially organized within the United States Weather Bureau because of a great demand for information regarding the relation of soils to meterological conditions (USDA, 1895, p. 26). The division was separated from the Weather Bureau in 1895 and became an independent agency within the United States Department of Agriculture. Leadership for this new publ

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new public agency was given to a young, energetic professor from South Carolina, Milton Whitney. According to Cline (1977) it was Whitney who was principally responsible for establishment of the Soil Survey in the United States and is his "lasting monument." Traveling through the northwest United States during August 1897, Whitney and Thomas Means, an assistant in the division, constructed a "detailed, large-scale alkali map" of an area near Billings, Montana (Whitney and Means, 1898). This was the nation's first soil survey. The practical applications of this early map so favorably impressed Whitney that he requested establishment of field parties to map on-site soil characteristics. The request was granted by Congress and the organized soil survey had its beginning in 1899 with the completion of three county surveys in widely scattered locations published at scales of one inch to the mile (Whitney, 1900).

The objectives of the Soil Survey have changed significantly throughout the years. The purpose of the early field operations was to provide maps for soil selection with emphasis on the adaption of soils to various crops. However, the predictive statements contained in these early county reports were quite general and contained very little specific information for users about management of soils. Kellogg (1961) indicates that most were little more than "descriptive statements based on field observations made during the course of field mapping." As the survey progressed, the trend has been towards including in the reports more precise statements about soils, predicting yields of adapted crops, grasses, or trees, and their probable responses under defined sets of management practices.

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Although the original purpose of soil surveys was to help make predictions chiefly in the agricultural field, people soon realized that soil maps were immensely valuable for uses other than agriculture. Early efforts in the United States centered on their use in guiding civilian highway construction and in defense planning (Kellogg, 1966). After World War II, it was increasingly apparent that the data contained in soil surveys not only could be used for providing information about agronomic purposes, but also to predict behavior of soils for various urban land uses.

The Soil Survey of Fairfax County, Virginia (Porter, *et al.*, 1963) is one of the earliest and most notable examples in which soil survey information was utilized for making urban soil interpretations. Although rather commonplace today, inclusion of multi-purpose soil interpretations in a county report for both agricultural and urban land uses was a marked departure from previous surveys. Commenting on this report, Cain (1967) concluded that:

> . . . the success of the use of soil survey in this county gave impetus to the use of soil survey in land use planning and application in urbanizing areas and it has served as a model for many other areas.

The numbers and volume of nonagricultural applications of soil survey data have increased dramatically over the last two decades. In 1965 a special program on this subject was organized for the Annual Meetings of the American Society of Agronomy and the Soil Science Society of America, and co-sponsored by the American Society of Planning Officials. The 19 papers presented at the meeting were later edited and published by the American

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Society of Agronomy in the popular book, Soil Surveys and Land Use Planning (Bartelli, et al., 1966). Continued interest in nonagricultural applications of soil survey data prompted the editors of the international soil science publication, Geoderma, to devote a special issue to this topic. Fifteen papers by leading international experts were assembled to illustrate various uses of soils information for urban planning and engineering. These papers were edited and later reprinted in Non Agricultural Application of Soil Surveys (Simonson, 1974). Together these two books represent the most comprehensive collection of papers illustrating applications of soil survey information to current problems in the planning of nonagricultural land uses. More importantly, however, they describe methods by which nonagricultural soil interpretations are currently prepared and presented to users of soil survey information for immediate use and application.

Problem Statement

As soil surveys have become more familiar to both professionals and layman alike, there has been an increased demand upon soil scientists to provide detailed and more quantitative predictions of soil behavior. Miller (1978) has observed that it has become increasingly apparent that simply providing individually colored factor-maps from interpretive tables in survey reports will no longer be sufficient to fulfill the needs of sophisticated user groups. The numbers of these people with completed soil surveys will continue to grow as many states embark upon accelerated soil mapping

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mapping programs.[1] Past methods of presenting soil interpretations will need to be changed if soil scientists are to meet the increasing needs of this enlarged audience provided with soil surveys.

For more than 15 years soil survey interpretations for non-agricultural land uses have followed a general procedure of rating soils by limitations. As described in the National Soils Handbook (SCS, USDA, 1978) a three-class system is commonly used, employing the terms "slight," "moderate," or "severe" to indicate a sequence of increasing limitations or problems that require solution before the soils can be used for the purpose indicated. "Slight" limitations are those which present no more than minor problems for a special use and can be overcome easily. "Moderate" limitations can be overcome by careful planning, special design, or maintenance for satisfactory performance. "Severe" limitations are difficult and costly to overcome requiring major soil reclamation, special design, or intensive maintenance. Ratings for proposed uses are usually given in terms of limitations and major restrictive features.

Information provided by soil limitation ratings is useful to sketch in broad perspective the magnitude of soil problems that users can expect. These ratings, however, do not necessarily indicate suitability since some limiting soil properties may not absolutely restrict certain land uses although they may limit soil performance. Some of these can be corrected feasibly, while others

[1]For example, in Michigan a new state law, the State Soil Survey Act (Public Act 268 of 1977), mandates that a minimum of 3,000,000 acres be mapped over the next ten years above SCS mapping.

cannot. A rating of severe then does not imply that a soil could not be used for the purpose indicated, but the cost of removing, replacing, or modifying the limitation or risk is extremely high. The guidelines for this system of interpretations gives recognition to the fact that most soil features can be modified or construction plans can be adjusted to compensate for most degrees of soil limitations (SCS, USDA, 1978).

Soil survey users have encountered increasing difficulties using interpretation ratings developed through current nationwide criteria (Slusher, Cockerham, and Mattews, 1974). It has been all too common for a community to survey its soils only to find that almost all soil areas have severe limitations for a variety of important urban land uses. Additionally, the soil ratings provided lack adequate information about the performance and cost of potential practices for overcoming these limitations in specific kinds of soils. In a very real sense, as McCormack (1974) has incisively written, professionals and laymen alike have been frustrated by this rather incomplete approach to soil survey education.

Planning officials and resource developers require increasingly detailed information from soil scientists concerning soil limitations and ways to alleviate them with site modifications or maintenance practices. For example, when told that a soil has severe limitations for residential dwellings because of a seasonally high water table, a building contractor will be immediately concerned with whether or not this hazard can be overcome, and at what cost in dollars and cents per dwelling. He will turn to the soil scientist to provide this kind of interpretative assistance. Unfortunately, most have been ill-equipped until recently to handle these requests adequately.

The concept of soil potentials is now being considered by the Soil Conservation Service as a new approach to help prepare these kinds of soil interpretations for survey users. It is an attempt to overcome the apparent deficiencies of the soil limitations concept by recognizing that certain soil hazards can be feasibly corrected through the use of innovative modern technologies. This approach could have far reaching consequences in the way soils information is presented to people. Rather than only pointing out problems, emphasis could be shifted to a more rewarding discussion of feasible alternatives and their costs for best achieving development potential in the physical environment of an area. The basic problem to which this study addresses itself is to develop a set of techniques which will help generate these ratings of soil potential for non-farm land uses, and also help to communicate these interpretations to soil survey users.

The problem this study examines is important for a number of reasons. First, the study adds to the sparse literature on soil survey interpretations and computer-generated interpretive soil maps. Second, it is one of the first studies to contribute towards development of procedures for preparing soil potential ratings. Finally, the study provides new insights and recommendations on future needs and actions on the concept of soil potential.

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Objectives of the Study

The general objective of this study is to develop a set of procedures by which ratings of soil potential can be generated, stored, and displayed in computerized-interpretive soil maps. This general objective has been further defined in terms of several more specific research objectives. These objectives are:

1. Survey the relevant literature to locate existing methods and techniques used to generate soil potential ratings and computerized-interpretive soil maps.

2. Describe and identify the kinds of practices or alternatives that may be used to overcome soil limitations, their costs, and continuing limitations that remain after corrective measures have been applied.

3. Develop a set of computer-assisted procedures to help prepare soil potential ratings for several major non-farm land uses.

4. Demonstrate the use of a computer software system to assist in the retrieval, manipulation, and display of stored soil potential ratings.

5. Make recommendations concerning future needs and actions on the concept of soil potential.

Description of the Study Area

The area selected for study in this research project was Windsor Township, Eaton County, located in the south-central part of the lower peninsula of the State of Michigan. The township was chosen because soils-related data were easily obtainable for this area. A detailed soil survey report had recently been published (Feenstra, *et al.*, 1978). The Remote Sensing Project at Michigan State University had also developed a computer-based natural resource information system for the township (Tilmann, *et al.*, 1977). This syste

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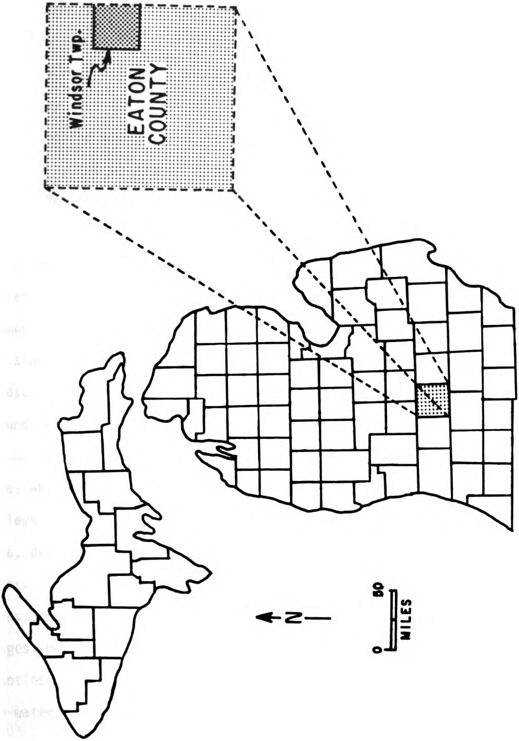
system had been successfully utilized both to assist the Tri-County Regional Planning Commission in regional water quality studies and general land use planning (Tri-County Regional Planning Commission, 1976) and the Eaton County Equalization Department in developing farmland assessment values. In addition, the location of the study area in relation to the Michigan State University campus and the City of Lansing made feasible interdisciplinary review of soil potential ratings by technical experts in appropriate state and county agencies, several university departments, and numerous professional organizations.

Figure 1-1 locates Windsor Township in relationship to Eaton County and the remainder of Michigan. The township is located in the central part of the state on the southwestern edge of the Lansing Tri-County metropolitan area of Clinton, Eaton, and Ingham counties. Windsor Township is bounded on the east by Delhi Township (Ingham County), and on the north, south, and west by Delta, Eaton Rapids, and Benton Townships (all in Eaton County), respectively. The City of Lansing, the state capital and major trade and industrial center of the region, penetrates the northeast portion of the township.

Physiography

Major surface features of the Tri-County and Windsor Township landscape are a direct result of continental glaciation which occurred between 10,000 and 2,000,000 years ago during the Pleistocene Epoch (Dorr and Eschman, 1970). Four times massive glaciers with thicknesses

Figure 1-1.--Location of Windsor Township in Eaton County and Michigan.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of more than several thousand feet slowly moved from the Canadian Highlands across the several Great Lakes basins, carrying southward all loose rock materials plucked and pryed from the landscapes over which they were moving. Each time the melting ice receded northward it left behind more glacial debris than before to be entirely reworked by the next major glacial advance.

The physical landscape features of the study area are primarily a result of glaciation during the most recent or Wisconsin Age which left Michigan about 10,000 to 12,000 years ago. The present flat or gently undulating surface of Windsor Township was formed during this period when stagnant or constantly receding ice slowly melted leaving behind glacial debris covering the landscape with a thick mantle of glacial drift. This drift or ground moraine represents the predominant glacial deposit encountered throughout the study area. Glacial meltwater channels formed at times when the ice melted rapidly are today occupied by broad swampy valleys in the area. Soon after the glaciers retreated from the area, depressions in these meltwater channels were covered by water. The highly favorable environment in and adjacent to such areas encouraged the growth of many plants, such as cattails, sedges, reeds, grasses, shrubs, and trees. These plants through countless generations grew, died, and sank down to be covered by the water in which they grew or to enrich surfaces of mineral soils. The depressions were eventually filled with these organic materials and became areas of peat and muck. The township is liberally dotted with these organic accumulations among the naturally better drained and more abundant mineral soils.

Topography and Drainage

The surface of Windsor Township is flat or gently undulating and slopes from west to east (Figure 1-2). The highest point in the township is located on top of Cunningham Hill in section 18, with an approximate elevation of 990 feet above sea level. The lowest point in the area is approximately 835 feet above sea level where the Grand River flows out of the township in section 2.

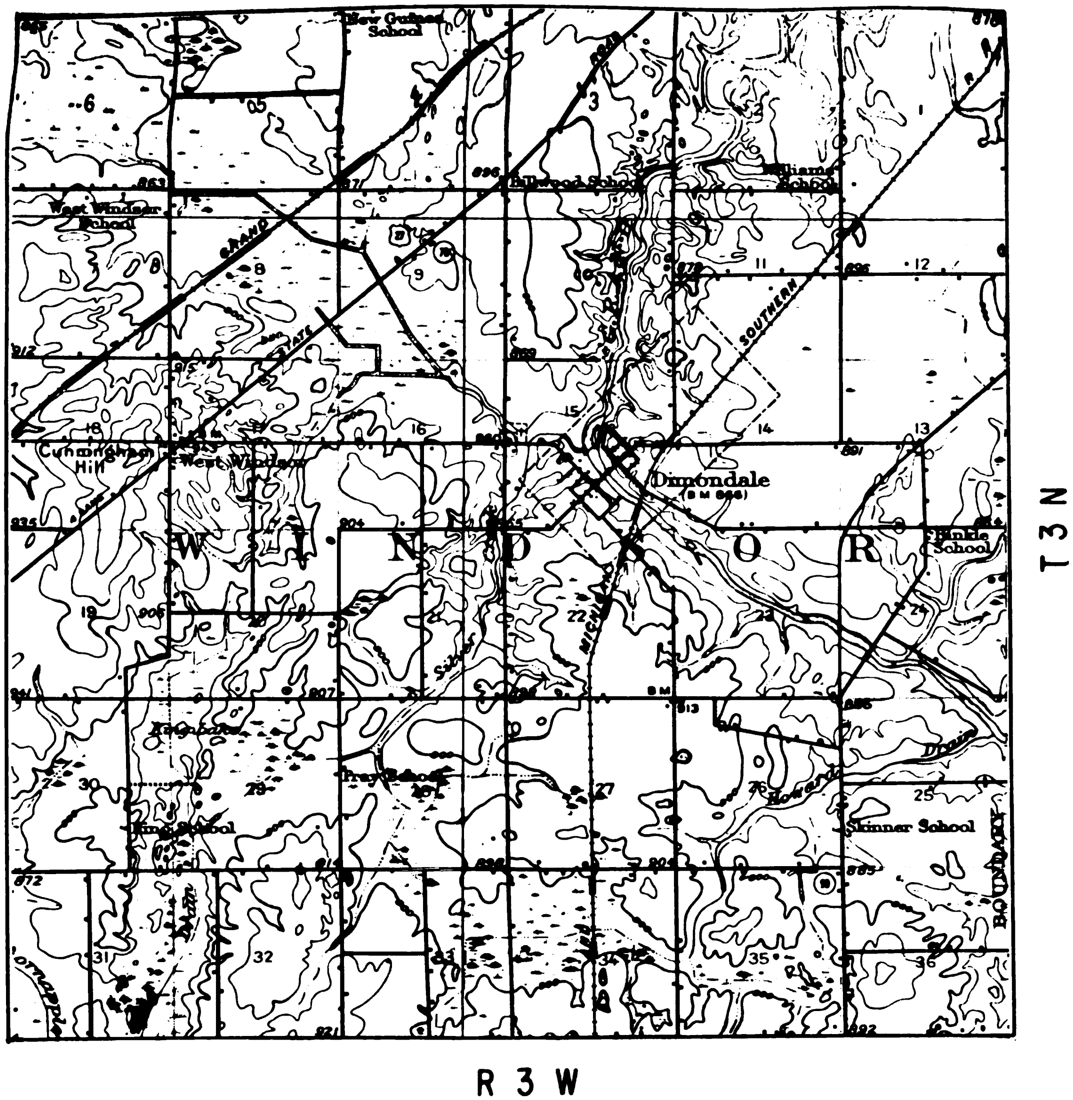
The township lies almost entirely within the Grand River drainage basin. The Grand River flows towards the northwest about 3 miles until it reaches the Village of Diamondale where it changes direction and flows northward. Most of the streams and drains within Windsor Township flow directly into the Grand River. The Thornapple River drains small portions, along several drains, in the western part of the township. The drainage pattern for the township is shown in Figure 1-3. This map also indicates those floodplain areas which may be subjected to periodic innundation by flood waters near the Grand River.

Soils

Soil includes the horizons near the land surface that differ from the underlying parent materials as a result of the combined interactions, through time, of topography, climate, living organisms and parent materials (SCS, USDA, 1975). The characteristics of a

Figure 1-2.--Topography of Windsor Township.

Source: Tri-County Regional Planning Commission, *Background For Planning*, 1967.



TOPOGRAPHY

WINDSOR TOWNSHIP
EATON COUNTY, MICHIGAN

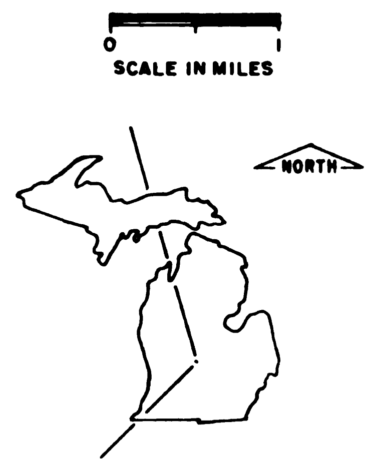
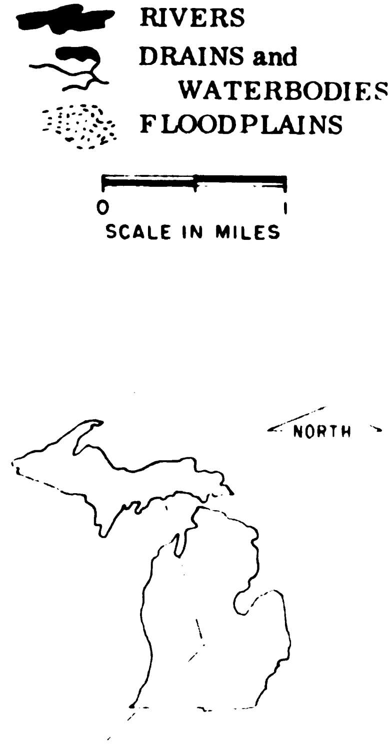


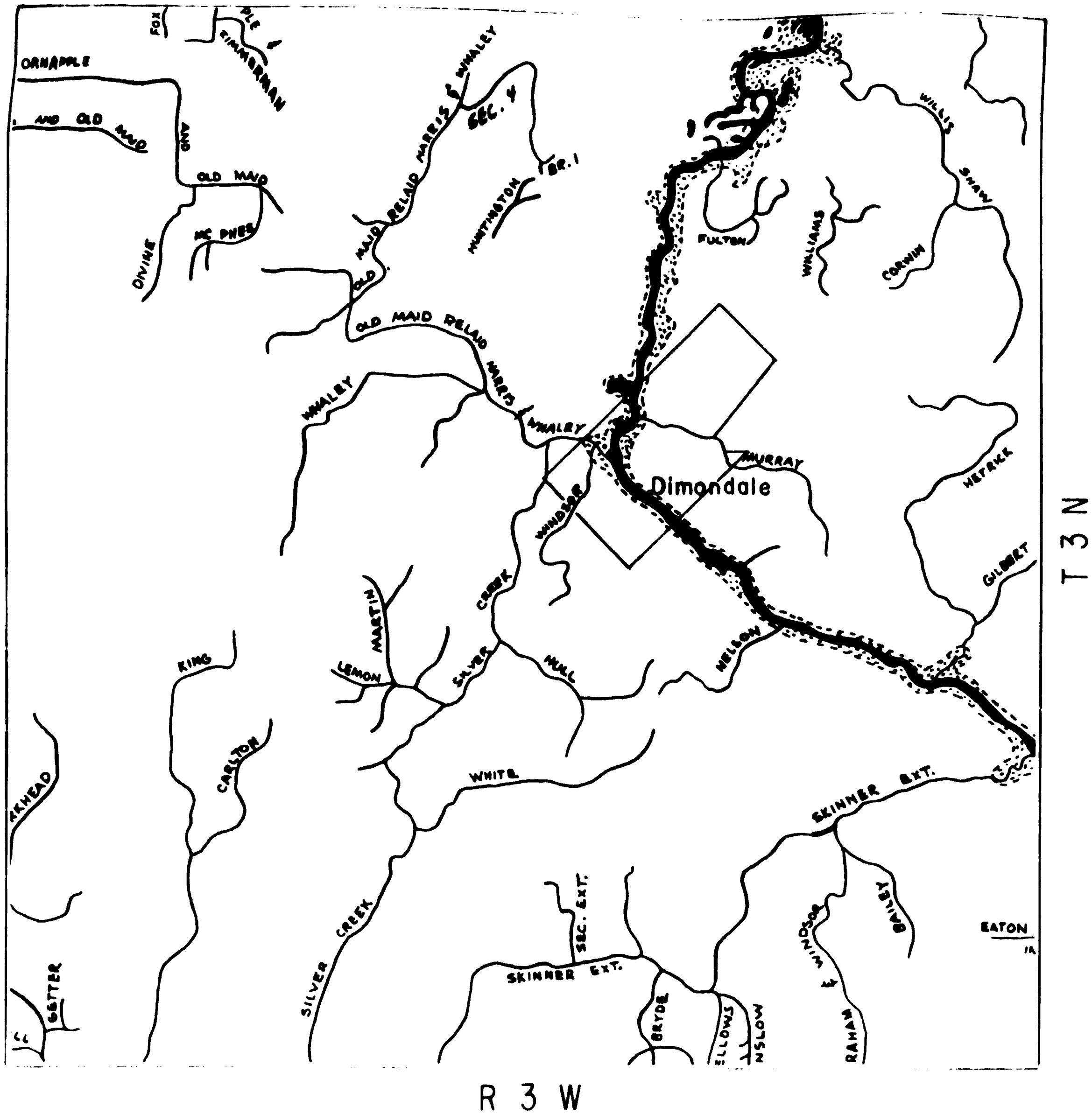
Figure 1-3.--Rivers, drains, and flood plains in Windsor Township.

Source: Tri-County Regional Planning Commission, _Background for Planning_, 1967.

RIVERS, DRAINS AND FLOODPLAINS

WINDSOR TOWNSHIP
EATON COUNTY, MICHIGAN





soil at any particular point in a landscape is determined by a unique combination of these five groups of soil-forming factors. The soils in Windsor Township, not unlike those elsewhere in Michigan, vary dramatically in the kinds and vertical sequences of profile horizons. Each horizon differs in texture, structure, color, chemical composition, thickness, and other properties to make up the soil profile.

For the purposes of mapping and classification, soil scientists have grouped soils with profiles which are almost alike into a single soil series. Except for textural differences in the surface layer (epipedon), all the soils in each series are described in terms of a single pedon that approximates the central concept of thickness, arrangement, and other important characteristics of the major horizons, plus the range in characteristics from that central concept. Each soil series is given a proper name, usually taken from the name of the town or the geographic feature near the place where the soil was first described or mapped, such as Marlette, Hillsdale, and Capac. In this manner, the soil series name identifies all soils in Michigan, or elsewhere in the United States, having characteristics which are essentially alike.

Soil management groups are groupings of the more than 400 soil series found within Michigan according to their dominant profile texture, natural drainage, and other special soil characteristics. The system places together soil series with similar profile characteristics, management requirements, and responses to management.

The soil management group concept was developed by the Michigan Agricultural Experiment Station, the Cooperative Extension Service, and the Soil Conservation Service working with the National Project in Agricultural Communications in Odessa Township of Ionia County in 1955 (Tilmann and Mokma, 1976). This statewide system in Michigan has been used to facilitate making crop and fertilizer recommendations and to help in nonagricultural land use decisions.

The interrelationship of the management groups of all the soil series described and mapped in Eaton County, including Windsor Township, are given in Table 1-1. The group numbers listed in the left hand column indicate the relative coarseness of the dominant mineral materials in the soil profile. The finer-textured clay loam and silty clay soils, for example, are listed at the top, accompanied by the number "1.5" (Lenawee series). Coarser-textured loamy sands are listed near the bottom identified with the number "4" (Boyer and other series). A fraction is used to indicate soils with contrasting textures in the profile (two-storied materials). The texture of the upper layer is represented by the numerator, and the texture of the lower materials is represented by the denominator. For example, 3/5 indicates soils which have 20 to 40 inches of sandy loam over sands and gravels (Bixby and other series). Lowland or alluvial soils (physiographic subdivision), which are stratified and subject to flooding, are indicated by the letter "L" preceding the profile texture (Shoals and other series). The capital "M" indicates peat or muck soils (organic composition). The symbol, M/m, indicates 16 to 51 inches of muck or peat over marl (Edwards

Table 1-1. Soil management groups of soils in Eaton County, Michigan.

Dominant Profile Texture, Physiography, or Composition	Natural Drainage Class				
	Mineral Soils of Different Textures and Natural Drainages			Organic (Muck) Soils (M) Very Poorly Drained	
	Well and Moderately Well Drained	Somewhat Poorly Drained	Poorly and Very Poorly Drained	16-51" thick	Over 51" thick
	a	b	c	c	
Clay loam or silty clay loam, 1.5			Lenawee		
Loam and silt loam, 2.5	Marlette Tuscola[1,2]	Capac Kibbie[2]	Parkhill Colwood[2]		
Sandy loam over clay loam to loam, 3/2	Owosso	Metamora			Houghton
Sandy loam, 3	Hillsdale			Palms	
Sandy loam, 20-40", over sand and gravel, 3/5	Bixby	Matherton	Sebewa		
Loamy sand 20-40", over loam to silty clay loam, 4/2	Metea				

Table 1-1. Continued.

Dominant Profile Texture, Physiography, or Composition	Natural Drainage Class: Mineral Soils of Different Textures and Natural Drainages — Well and Moderately Well Drained (a)	Somewhat Poorly Drained (b)	Poorly and Very Poorly Drained (c)	Organic (Muck) Soils (M) Very Poorly Drained — 16-51" thick (c)	Over 51" thick
Loamy sand, 4	Boyer Bronson Oshtemo Spinks	Brady Wasepi	Gilford	Adrian	
Lowland areas, loamy, L		Shoals	Sloan Cohoctah		
Mucks or peats over marl, M/m				Edwards	
Loam, 20-40" over bedrock, 2/R	Winneshiek				
Sand to loamy sand, 20-40" over bedrock, 4/R		Wasepi Variant[3]			

[1]Moderately well drained with mottles in the lower B and in the C horizons.

[2]Stratified with very fine sands and silts, -s.

[3]Bedrock variant of Wasepi soil series.

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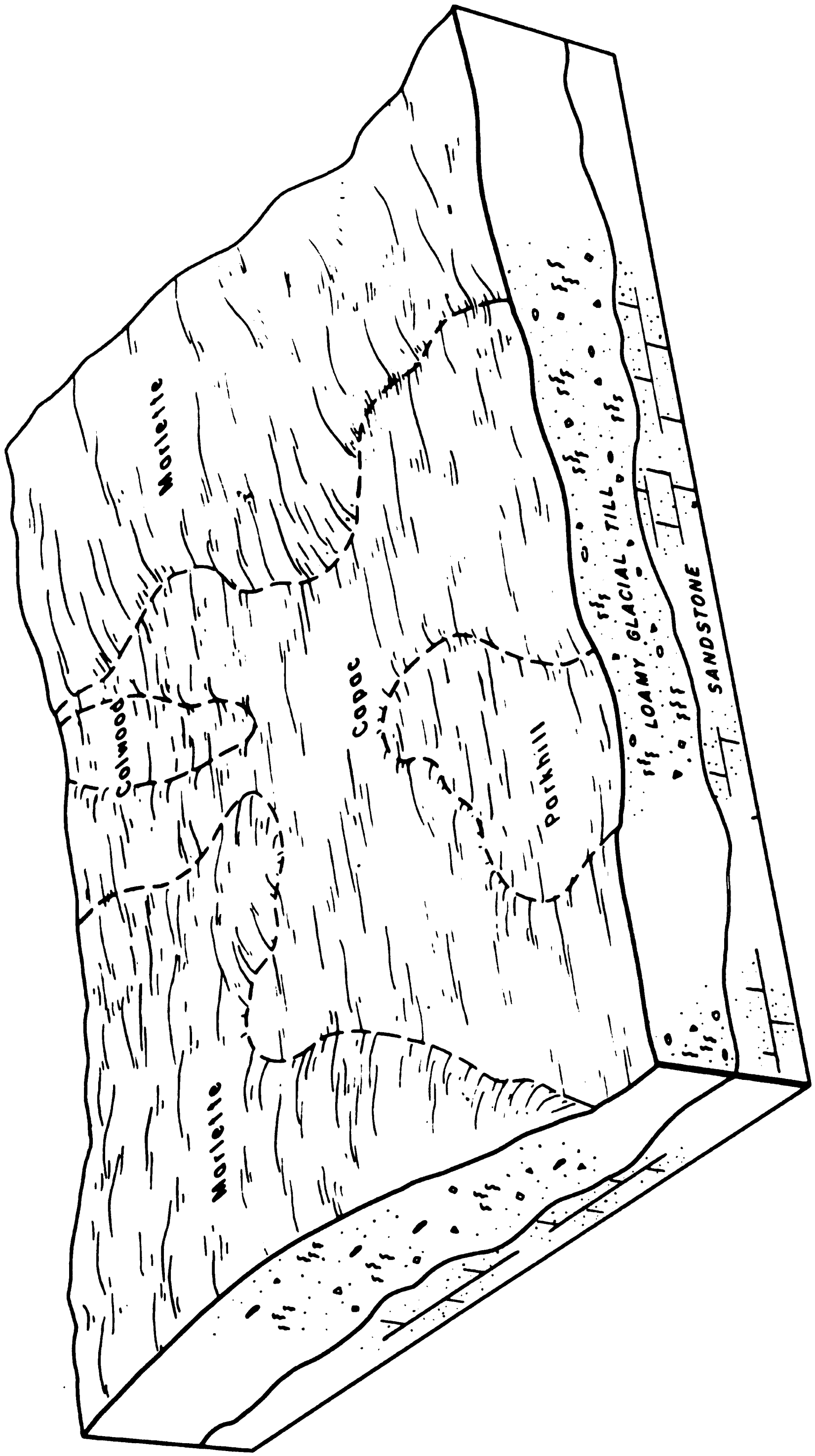
series). Soils having 20 to 40 inches of loamy soil material over bedrock (R) are represented by a symbol similar to a two-storied soil. For example, 2/R, indicates loam, 20 to 40 inches, over bedrock (Winneshiek series).

The lower case letters shown in the column headings across the top of the table indicate the natural drainage under which the soil profiles developed. Well and moderately-well drained soils are represented by the letter "a" (e.g., Marlette to Winneshiek series, Table 1-1). Somewhat poorly drained soils are represented by the letter "b" (Capac to Shoals series). Poorly and very poorly drained soils are represented by the letter "c" (Lenawee to Cohoctah series).

Soils formed from similar parent materials and differing only in natural drainage and topography are defined as a toposequence of soils. Several of these are shown on separate lines in Table 1-1. For example, the Marlette- Capac- Parkhill sequence is listed on the same line in the 2.5 soil management groups. Similarly, the Tuscola, Kibbie, and Colwood series on the next line are developed in stratified very fine sands and silts in the soil management groups with similar drainage; 2.5 a-s, 2.5 b-s, and 2.5 c-s, respectively. Figure 1-4 is a vertical cross-section illustrating the topographic association of these soils of these toposequences in Eaton County. The well-drained and moderately-well drained Marlette soils occupy gently sloping to steeply sloping positions in the landscape which receive little runoff from adjacent lands. The somewhat poorly drained Capac soils occupy the nearly level to

Figure 1-4.--Topography, soils, and underlying material in Marlette-Capac-Parkhill toposequence.

Source: Feenstra, et al., Soil Survey of Eaton County, Michigan, 1978, p. 5.


Marlette
Colwood
Capac
Parkhill
Marlette
LOAMY GLACIAL TILL
SANDSTONE

gently undulating positions in the landscape which commonly receive runoff from areas of Marlette soils at slightly higher elevations. The poorly drained and very poorly drained Parkhill soils (or Colwood in stratified materials) occupy the nearly level positions in the landscape in narrow drainageways and depressional areas which receive runoff from surrounding Capac soils.

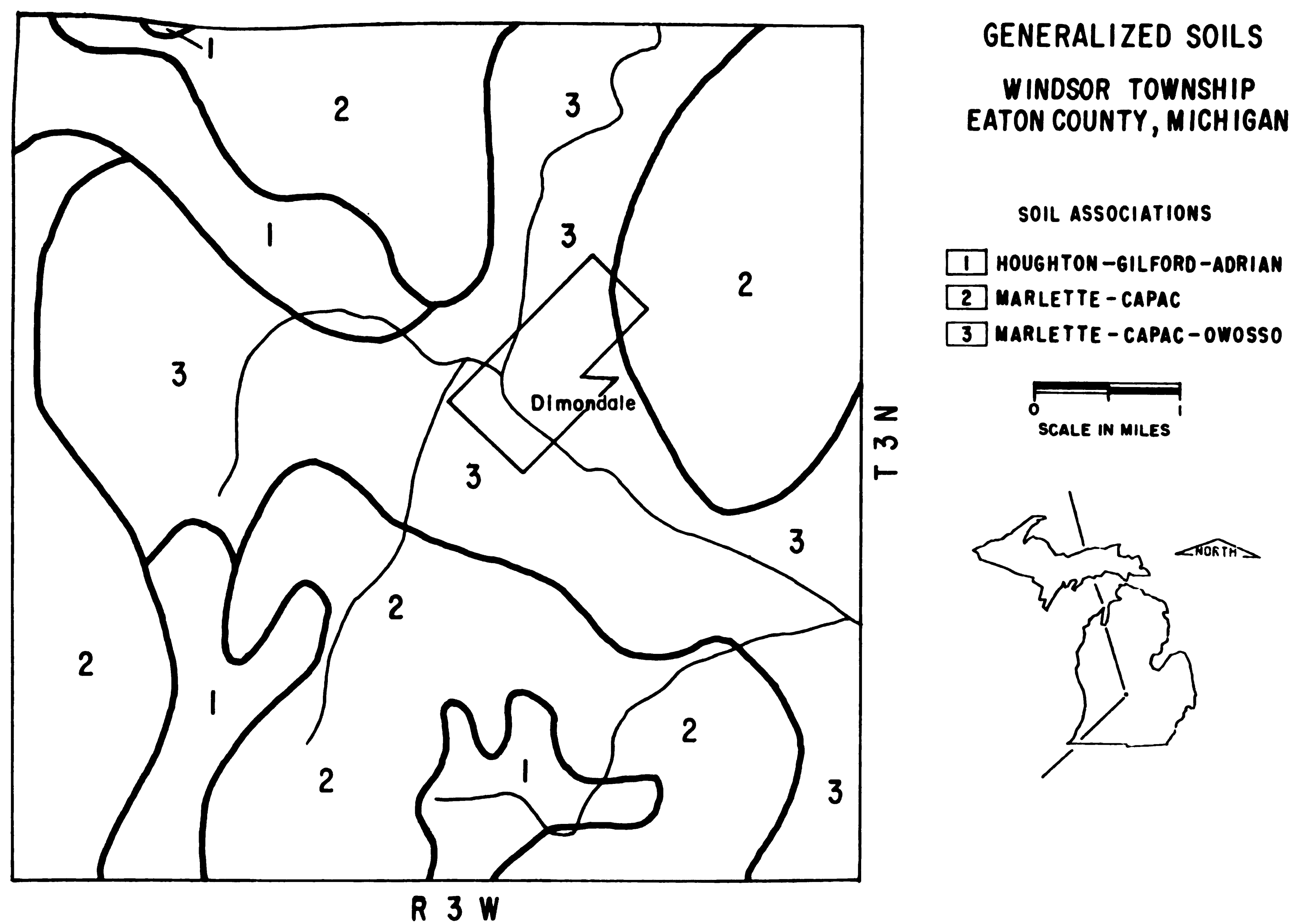
With these facts about the soils in a locality and the way they occur on the landscape, it is possible to make a general map that shows several main patterns of soils, defined as soil associations (Figure 1-5). Each association is a landscape not unlike the one illustrated in Figure 1-4. Soils within any one association may differ greatly among themselves in several characteristics such as slope, natural drainage, or solum depth. Thus, a general soils map does not show the kind of soil at any one place, but groups of associated soils each part of which has in it several kinds of soil.

Soil associations, as a rule, are named for the major soil series in them, but soils of other series may also be present. The legend on the soil association map for Windsor Township (Figure 1-5) shows the names of the major soils in each soil association area. Those areas are described below. Descriptions of the individual soils series noted in this discussion are briefly summarized in Appendix A.

1. Houghton-Gilford-Adrian Association
   Nearly level, very poorly drained, mucky and loamy soils in glacial drainaqeways.

Figure 1-5.--General soils map of Windsor Township, Eaton County, Michigan.

Source: Feenstra, *et al.*, *Soil Survey of Eaton County, Michigan*, 1978.


GENERALIZED SOILS
WINDSOR TOWNSHIP
EATON COUNTY, MICHIGAN
SOIL ASSOCIATIONS
1 HOUGHTON-GILFORD-ADRIAN
2 MARLETTE-CAPAC
3 MARLETTE-CAPAC-OWOSSO
0
1
SCALE IN MILES
NORTH
T 3 N
R 3 W
Dimondale

This association makes up about 15 percent of the township, or 3,456 acres. It is about 45 percent Houghton soils, 20 percent Gilford soils, 15 percent Adrian soils, and 20 percent minor soils such as Colwood, Sebewa, Boyer, Oshtemo, Spinks, Wasepi, and Edwards soils.

This association occupies three main areas in the township. One area straddles "Old Maid Swamp" in the northwest portion of the township. Another elongated area is situated along King and Carleton drains (Figure 1-3) in the southwest portion of the township. The remaining area is located almost entirely in section 34, along the upper Skinner Drain Extension (Figure 1-3).

2. Marlette-Capac Association
Nearly level to gently undulating, well drained to somewhat poorly drained, loamy soils on till plains.

This association occupies approximately 55 percent of the township, or 12,672 acres. The well drained and moderately well drained Marlette soils, found on gently sloping to gently undulating locations, occupy 40 percent of the area. The somewhat poorly drained Capac soils account for 30 percent of the area. Minor soils such as Parkhill, Colwood, Sebewa, and Houghton occupy 30 percent.

The dominant soils of the association are used for growing cash crops and in dairy operations. Some drainage is needed on the wetter soils, but response to tile is good with the drained soils producing as well as or better than the drier soils. Many farm areas in this association near major highways are being developed for urban land uses. These are prime agricultural areas.

3. Marlette-Capac-Owosso Association
   Nearly level to hilly, well drained to somewhat poorly drained loamy soils on moraines and till plains.

The most extensive portion of this association are found in the central part of the township. It occupies approximately 30 percent of the township, or about 6,912 acres. The well drained and moderately well drained Marlette soils, found on gently sloping to hilly locations, occupy 42 percent of the area. The poorly drained Capac soils account for 23 percent of the association. Minor soils such as Boyer, Hillsdale, Spinks, Bixby, Houghton, Shoals, Sloan, Owosso, Parkhill, and Metamora occupy 35 percent.

Dairying and cash crops are the important enterprises on the dominant soils of the association. Many farm areas, however, near the village of Diamondale and major highways are reverting to urban land uses.

Land Use

Eaton County has been recently mapped employing a classification scheme with 21 categories of land use/cover (Tri-County Regional Planning Commission, 1976). The map was prepared by interpreting color-infrared aerial photographs taken of the entire Tri-County area during 1972. The smallest unit outlined and classified on the map is an area about 10 acres in size.

Table 1-2 presents a tabular summary of the land use/cover data obtained from this map for Windsor Township. The data indicates the overall pattern of land use and development within the area. As can be seen, by far the largest amount of land in the township, about

Table 1-2. Acreage distribution of land use/cover categories in Windsor Township, Eaton County, Michigan, 1972.

Land Use/Cover Category[1]	Acres	Percent of Total
Agriculture		
Cultivated cropland	9,300	40.4
Pasture	7,840	34.0
Bush fruits	140	.6
Tree fruit	20	.1
Total	17,300	75.1
Forest		
Broadleaved forest	1,580	6.8
Coniferous forest plantations	160	.7
Mixed forest	20	.1
Total	1,760	7.6
Range		
Brushland	1,510	6.6
Total	1,510	6.6
Wetlands		
Forested wetlands	630	2.7
Nonforested wetlands	620	2.7
Total	1,250	5.4
Urban		
Residential	780	3.4
Transportation and utilities	260	1.1
Extractive	40	.2
Commercial and Institutional	50	.2
Other Urban	20	.1
Total	1,150	5.0
Water		
Open Water	70	.3
Total	70	.3
Total acreage	23,040	100.0

[1]For definitions of these land use/cover categories, see Office of Land Use, Michigan Department of Natural Resources, Michigan Land Use Classification System, 1974.

SOURCE: Remote Sensing Project, Michigan State University, "Interpretive Guidelines and Technical Specifications For the Windsor Township Resource Management Portfolio," 1976.

75 percent, is devoted to agriculture. More than 50 percent of this agricultural land (40.4% of the ownership) is planted to crops and tilled annually. The remaining agricultural acreage is predominantly used as permanent pasture in dairy operations.

Population

Windsor's population has been increasing at a rapid rate since 1930 with the most significant growth occurring after 1920 (Table 1-3). This growth can be attributed to the post-World War I "baby boom," surburbanization, and the rapid expansion of the Oldsmobile assembly plant, Michigan State University, and state agency staffs in the City of Lansing. In the next 20 years the population is expected to continue to increase resulting in a population of 6,391 by the year 1996 (Table 1-3). Along with the increase in population, it is projected that there will be increases in the numbers of residential dwellings in the township (Table 1-4). These new homes will be constructed throughout the township, although the majority will be concentrated in the Village of Diamondale, the northeast corner of the township near the City of Lansing, and along US Highway 27.

Overview of the Study

A brief chapter-by-chapter overview of the five chapters in this research study is provided here.

Chapter I deals with an introduction and delineation of the problem; the problem statement, the objectives of the study, a description of the study area, and an overview of the study.

Table 1-3. Windsor Township population trends.

Year	Population	Numerical Increase	Percent Increase
1900	1,497	--	--
1910	1,447	- 50	- 3.3
1920	1,334	-113	- 7.8
1930	1,798	464	34.7
1940	2,114	316	17.5
1950	2,628	514	24.3
1960	3,320	592	22.5
1970	3,513	193	5.8
1976	4,359	856	24.4
1981	4,725	366	8.4
1986	5,295	570	12.1
1991	5,857	562	10.6
1996	6,391	534	9.1

SOURCE: Tri-County Regional Planning Commission, <u>208 Water Management Plan: Interim Outputs</u>, 1976.

Table 1-4. Windsor Township dwelling unit trends.

Year	Dwelling Units	Numerical Increase	Percent Increase
1970	1,098	--	--
1976	1,377	279	25.4
1981	1,497	120	8.7
1986	1,681	184	12.3
1991	1,861	180	10.7
1996	2,036	175	9.4

SOURCE: Tri-County Regional Planning Commission, <u>208 Water Management Plan: Interim Outputs</u>, 1976.

Chapter II consists of a review of related literature relevant to the dissertation topic. Section one is a review of the literature in the area of soil potential ratings; section two treats the literature related to computer-interpretive soil maps.

Chapter III describes the research methods and procedures used to generate ratings of soil potential for several land uses and their spatial display using a computer software system.

Chapter IV deals with the presentation and analysis of the data.

Chapter V presents a summary of the study, draws conclusions about the research findings, and makes recommendations about possible areas for future research.

CHAPTER II

REVIEW OF RELATED LITERATURE

As outlined in Chapter I, this research has two primary concerns. The first is to develop a set of techniques which may be used to prepare ratings of soil potential for non-farm land uses. The second is to develop methods for the spatial display of these ratings by use of computer-drawn interpretive soil maps. It follows that research had to be conducted to discover existing methods and techniques, and to analyze their potential advantages or disadvantages. The first section of the chapter reviews the historical development of the soil potential concept and current applications in soil survey interpretations. The later section of the chapter presents a review of the state of the art in computer-interpretive soil maps.

The Soil Potential Concept

By the early 1970s many regional offices of the United States Soil Conservation Service (SCS) were being approached with requests for information regarding the suitability of soils for nonagricultural land uses and the measures and costs involved in making them suitable. At the same time, there was also greater recognition by those involved in soils interpretations within the

Cooperative Soil Survey that their method of rating soils by limitations no longer fulfilled the information needs of many users. A concerted effort began about 1970 to develop a new concept of soil survey interpretations focusing on the quality of a soil after measures to correct limitations relative to other soils in an area have been applied.[1] Taff (1972) gives an excellent review of two early research efforts undertaken in St. Croix, Virgin Islands and the New Orleans metropolitan area.

The results of the St. Croix study were first presented by Bartelli (1972) at a National Cooperative Soil Survey Workshop in Texas. This was one of the early attempts, if not the first, at developing ratings of kinds of soil according to their performance after measures are installed to compensate for soil limitations. Table 2-1 presents some of the data collected for several soils which are mapped in St. Croix. The development costs listed were not actual dollar costs for each related use, but were rather based on qualitative estimates collected from contractors operating in St. Croix. The ratings shown (low, moderate, and high) thus reflected the need for certain measures on some soils, but not needed on others for a given land use. The soils were also evaluated in terms of their aesthetic values (slopes, vistas) in urban development and the probable impact this development would have on the environment. A three-class system was used, employing the terms, "low," "moderate," and "high,"

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[1]Personnal communication with Donald E. McCormack, Director of Soil Survey Interpretations Division, Soil Conservation Service, Washington, D.C. on November 30, 1978.

Table 2-1. Ratings of soil potential for urbanization for several soils in St. Croix, Virgin Islands.

	Cost of Development[1]				Benefits[2]		
Soil Unit	Land Development	Utilities	Roads	Housing	Asthetic Value	Maintenance	Potential
Aguilita	Moderate	Moderate	Low	Low	High	Low	Strong
Hesselberg	Low	High	Low	High	Moderate	Low	Good
Fredensborg	Moderate	Low	Moderate	Moderate	Moderate	Moderate	Moderate

[1]Cost of Development--Costs were based on key operations and contractors operating in the area. Actual dollar costs were difficult to obtain, but certain key operations were used.

[2]Benefits--Asthetic values (slopes, vistas) and maintenance costs (flood protection, unstable soil, etc.) are considered as part of the impact on environment. Other environmental effects are extended life of dwellings, dry basements, and long lasting roads and streets.

SOURCE: Taff, 1972, p. 17.

to signify degrees of benefits. The overall rating of soil "potential" or suitability for these soils is reflected as "strong," "good," "medium," and "low." Bartelli fails to indicate how these last ratings were developed, so presumably one can conclude that they were based on "good judgement" rather than any quantitative rating system.

A different method of soil interpretations for urban development from that in St. Croix has been described by Slusher, Cockerham and Mattews (1974) in their soil survey of the metropolitan area around New Orleans, Louisiana. This survey area covered nearly 50,000 acres (20,250 ha) of portions of four parishes where the Regional Planning Commission expected new urban growth to develop during the period from 1968 to 1988. These planners were interested in obtaining useful soils information which could help them propose rational development of this area. The survey party faced many uncertainties in carrying out this study for few detailed soil surveys had ever been made in swampy and marshy areas, even in the southeastern United States, and the kinds of soil differences and their implications for urban uses were not well understood at that time. The team developed an interesting set of mapping and sampling techniques for this rather difficult assignment, and the reader is referred to Slusher, Cockerham, and Mattews (1974) for a fascinating account of these innovative methods and procedures.

More germane to this discussion is a description of the system these researchers used to prepare engineering and other land use interpretations. Engineering interpretations of the 19 mapping units in the survey were first prepared according to the national guidelines published in the Guide for Interpreting Engineering Uses of Soils (SCS, USDA, 1967). The degree and kinds of soil limitations for several uses were listed in tabular form. In addition to providing these rather common types of soil interpretations, the soils were then arrayed by groups and within major groups in order of their increasing limitations for most urban uses after drainage and protection from flooding. The following set of soil properties were considered in arraying the soils into six major groups: (i) consistence of mineral layers, (ii) contents of mineral and organic matter, (iii) thickness of organic layers, and (iv) presence of buried logs and stumps. The soils placed in the first group were considered to be most desirable for urban development even though their limitations ranged from moderate to severe. The soils in each succeeding group were assumed to have limitations which were more difficult or costly to overcome.

These researchers did not use elaborate or complex weighting schemes to group soils for land use interpretations as did others in some later studies. They relied on their knowledge of the behavior of these soils to help them place the soils into each group. The soils were not rated according to their estimated costs for development or probable continuing limitations. This should not, however, totally negate the usefulness of the research. It is noteworthy for being one of the first studies to provide soil survey users in an urban region with additional interpretations setting forth important differences between soils with severe limitations for urban development. The study is somewhat similar to the one undertaken in St. Croix because presumably "good judgement" rather than any quantitative rating scheme was used to prepare the ratings of soil suitability and potential.

Quantitative Movement to Derive the Ratings

Kloosterman and Lavkulich (1972) present a method for quantitatively preparing soil interpretations for agricultural and engineering land use. They reviewed available literature to develop a concept or model of the ideal soil and its properties for cash cropping and roadbed construction. An actual soil in nature will rarely fit these models precisely and inputs will be necessary to modify it to resemble the model soil. The researchers assigned arbitrary treatment costs to soil properties, which were deemed important for each land use, to calculate an estimate of the input costs required for each soil. Factor analysis was used to reduce the set of variables into a subset of underlying influences. Regression equations were derived from the variable factor loadings to give factor loadings for each individual soil. Each soil can therefore be represented as a point in n - dimensional space. The Euclidean distance between each soil and the model was calculated to determine a similarity index by which soils were rated for suitability in cash cropping and roadbed construction.

This study differs from those previously discussed by its highly quantitative approach and innovative use of various statistical techniques. The methods developed by Kloosterman and Lavkulich are quite fascinating and obviously, in this author's opinion, had great impact on other researchers at the time the paper was first published. It is one of the first of many studies in the early 1970's to utilize a quantitative approach to derive ratings of soil potential. Although the study suffers from its reliance on purely hypothetical and arbitrary assignment of costs for treating soil hazards, it vividly illustrates how quantitative methods and statistical techniques can be brought to bear on the problem of preparing ratings of soil potential. Studies which soon followed emphasized this quantitative approach.

Increased interest within the National Cooperative Soil Survey for a suitability classification system of organic soils for various land uses led to the formation of the National Task Force on Organic Soils in June 1972. They were charged with preparing a set of interpretation guides on the following: (1) management suitability groupings and ratings for specific crops; (ii) development difficulty ratings; (iii) forestry; (iv) planning purposes; and (v) commercial uses of peat. In a report to the 1973 National Work Planning Conference of the National Cooperative Soil Survey, the Task Force proposed that these guides take the form of a numerical rating system with penalty points assigned for adverse conditions. The penalty points were to be tallied to give a single numerical rating. According to this system organic soils with the highest numbers presented poorer soil conditions for a given land use. An alternative format was proposed which placed the highest numerical ratings on the most suitable organic soils. After further work and additional testing, the interpretation guides were again considered by the Organic Soils Committee (Committee 3) of the Cooperative Soil Survey and published in the 1975 report of the National Technical Work Planning Conference (SCS, USDA, 1975a). The interpretation guides were generally well received at that time, but further regional testing was deemed necessary before the guides were again evaluated.

Although the original purpose of the guides was to help rate organic soils for potential in agricultural and urban land uses, soil scientists in the National Cooperative Soil Survey soon realized that its penalty point approach would also be extremely useful to help prepare similar ratings of mineral soils. As an example, ratings of soils in Spartanburg County, South Carolina (Camp, 1968) were used to illustrate the penalty point approach (Bartelli and Ikawa, 1975). The objective in that study was to develop a "potential index" to rate soils, using urbanization and wood production as examples. The rating procedure was similar to that proposed by the Organic Soils Task Force (SCS, USDA, 1972). Numerical ratings were assigned to different soil factors which influence potential forest production and urban land development. Soil characteristics with the least limitations for the selected use were rated 1 and those with very severe limitations were rated 10. The sum of the component indices was obtained through use of the following equation:

$$SPI = \sum_{i=1}^{n} W_i \; I_i$$

where SPI = Soil potential index

W_i = Index weight for factor i

I_i = Value of index for factor i

The ratings of each soil factor were therefore added together to give a numerical index value ranging between 1 and 100 for each soil map unit. This final rating is the soil potential for the specified land use of each soil mapping unit. Soils with the least limitations had the smaller numbers; those with more limitations had higher numbers. These soils were then grouped according to a three-class qualitative system, employing the terms "well-suited," "suited," and "poorly suited."

The criteria used to weight the overall importance of each factor for any use in question was essentially good judgement supplemented by basic research data. As Bartelli and Ikawa (1975) wrote:

> The W factor allows for judgement input. The soil scientists who is rating a soil for a particular use has the opportunity to reflect the experience and knowledge of the land users in the survey area . . . and the experience of the land manager.

This study provides one of the first mathematical models for determining soil potential for any use in question. The general equation, SPI $\sum_{i=1}^{n} W_i \; I_i$, gave soils a quantitative rating which was used to array them in order of their "best fit" for specified uses. The values for W and I can represent the everyday experiences of soil survey users within an area, rather than national guidelines. This was a clear extension of soil interpretations beyond the identification of the kind or degree of soil limitations.

Although this mathematical approach provided a simple listing of soil potential, many soil scientists soon recognized that this information would no longer continue to satisfy a major segment of soil survey users. Bouma (1974) proposed that emphasis be shifted away from only describing soil limitations and potentials in an area towards defining the means and alternatives for realizing it. He argued for including with the ratings of soil potentials descriptions of "alternative construction and management packages" for overcoming soil limitations. Similar to Bouma's comments, McCormack (1974) wrote:

> . . . it is essential that the practices that might be used to overcome the soil limitation be identified, as well as their cost, and an estimate of any continuing limitation after they are installed.

These recommendations and suggestions were incorporated into draft guidelines of the Soil Conservation Service for developing soil potential ratings. Provisional standards were presented by Bartelli (1975) at the 1975 National Work Planning Conference of the Cooperative Soil Survey and outlined in National Soils Handbook, Notice 3 circulated among soil scientists later that year.[2] These were the following:

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[2] National Soils Handbook, Section 404, "Guide For Overcoming Soil Limitations and Developing Soil Potentials," May 5, 1975.

1. Soil potential ratings are developed within the context of the soil mapping unit. They do not consider location, market trends or socio-political forces.

2. The rating for a soil will not be standardized, country wide. The same soil may have a different rating within two separate soil survey areas. Its position in order of degree of suitability is determined by the ratings of other soils in the area.

3. Supporting text is required to further define and explain the procedures used and to present the basic data upon which the evaluation is founded. Improvements for overcoming soil limitations are considered where feasible. This points out the need for collecting qualitative data on overcoming soil limitations and maintenance of improvements. Local information about "what works" in overcoming soil limitations must be recorded by kinds of soil.

4. Define clearly the land use classes.

5. Identify the practices that might be used to overcome soil limitations. Also, include a general idea of their cost and an estimate of any continuing limitations after they are installed.

While the draft guidelines were being circulated among soil scientists, efforts were well underway in Florida, Texas, Washington, D.C., and several other areas to develop local approaches for interpreting soils in terms of their potential for a particular use. The general aim of these studies was to get around the notion resulting from the soil limitations concept that soils having severe limitations could not be used. Alternative numerical and qualitative rating systems were used in these studies to arrive at the predictions of soil potentials. Procedures varied from those outlined in the draft nationwide guidelines. For example, criteria used for rating soils did not always include consideration of alternative treatment for overcoming soil limitations, their costs and expected performance, and continuing limitations.

Johnson, et al., (1975) rated soils which were mapped and described in Seminole County, Florida according to their potential for 14 specific land uses. Soils were grouped into one of five categories ranging from very high to very low potential based on their numerical ranking. This was determined by assigning positive points to soil properties which affect a particular use, multiplying each point by a weighting factor, and then tallying the total product. Soil properties considered most favorable were assigned a point value of 5, while those less favorable were assigned values of 4, 3, 2, 1, or 0. Those properties considered most unfavorable were assigned the latter value. According to these researchers, the weighting factor was used to "maneuver or weight the properties so that a soil with all favorable properties will have a numberical ranking of 100." The highest numerical point totals were therefore assigned to those soil properties that the researchers considered to have the most effect on the particular use.

The supplement to the published survey (Johnson, et al., 1975) included information about each soil as to its limitations, potentials, and the necessary practices to obtain its potential for the selected land uses. These were listed respectively in adjacent columns. Estimated costs for overcoming soil limitations and predictions of continuing limitations in use were not provided for each soil.

Soils in Harris County, Texas were also numerically rated according to their potential for selected land uses (Wheeler, et al., 1976). They were later arrayed in one of five categories ranging from very high to very low potential. These interpretations were included in the soil survey report rather than a soil survey supplement like that of Seminole County, Florida.

Soil potential ratings were prepared by use of an additive system of negative points assigned to unfavorable soil properties. Soils were individually rated for the following urban land uses: dwellings without a basement but with a public sewer system, streets, shallow excavations in which to place utilities, and uncoated steel pipe. These numerical ratings were summed to determine an overall soil potential for "urbanization." The system does not appear to note or rate continuing limitations. In addition, no information was provided about practices or treatments to overcome soil limitations, their costs, and potential performance.

A non-numerical approach for rating soil potential was used in the Soil Survey of the District of Columbia (Smith, 1976). Soil associations, and not the individual soil mapping units of the survey, were rated according to their potential for major land uses. These were rather broad classes such as landscaping, vegetable gardens, urban uses, intensive recreation, and extensive recreation areas. The system used to assign the qualitative ratings was not discussed in the report. Placement of each soil association into one of the three categories (good, fair, or poor) of soil potential was probably based upon "good judgement" rather than any specific criteria. There was no mention of suggested treatments for overcoming soil limitations, as well as continuing limitations remaining after these treatments or measures are adopted. The ratings appear to be related exclusively to soil limitations rather than based upon treatments, costs, expected performance, and continuing limitations.

Soil Potential Task Force

In late 1976, a Washington office task force committee in the SCS was appointed, chaired by Lindo Bartelli, to develop a policy statement and revised guidelines for implementing the soil potential concept.[3] The impetus for this committee resulted from a concern by many in the Soil Survey that national coordination was desirable given the results of uncoordinated and unguided efforts at that time in Florida, Texas, and other states. The Task Force was charged with developing model guides and procedures for preparing soil potential ratings which would be included in documents published with SCS participation such as soil survey manuscripts or technical guides.

The committee thoroughly reviewed the experiences of soil scientists in several states actively engaged with the soil potential

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[3]Personal communication with Lindo J. Bartelli, Director of Soil Survey Interpretations Division, Soil Conservation Service, Washington, D.C. on December 10, 1976.

concept at that time (SCS, USDA, 1976). They weighed the relative advantages and disadvantages of the many alternative rating systems utilized in these projects. They also reconsidered the broad guidelines first issued in 1975 in the National Soils Handbook (Notice 31) for preparing ratings of soil potential. The committee tentatively agreed that the final guidelines for the soil potential rating system would incorporate the following criteria:

1. Soil potentials should be listed in conjunction with limitations;

2. Ratings should be for the mapping unit regardless of map scale or contrast of components;

3. Mapping units of detailed surveys may be rated for specific or general land uses (dwellings, septic tanks, corn, recreation, etc.).

4. Mapping units of general soil maps should be rated only for broad land uses (cropland, urbanland, etc.); and

5. Users should be presented with:

   a. soil limitations

   b. treatment alternatives

   c. continuing limitations after treatment

   d. relative treatment costs and performance expected through array of best to worst

   e. adjective ratings assigned locally.

A preliminary draft of Parts I and II, Section 404 of the National Soils Handbook, "Guides for Preparing Soil Potential

Ratings," was written during the early spring of 1977. The Task Force sponsored a conference on soil potential for septic tank filter fields March 1-2, 1977 at the University of Tennessee in Knoxville to test these proposed guidelines.[4] Participants included representatives from the Soil Conservation Service, the Tennessee Department of Public Health, and the University of Tennessee. They considered the basic concepts developed by the Task Force and attempted to apply them to soil conditions in Tennessee.

The participants prepared ratings of soil potential for several common soil mapping units in Tennessee (Table 2-2), identified a suitable kind of filter field along with other needed treatments for each, and listed any continuing limitations. Costs of these systems were assigned, as well as a cost for continuing limitations. These costs were in relative numbers rather than in actual dollar amounts computed from construction estimates of labor and materials. "Good judgement" on the part of conference participants formed the basis of the assignment of these cost indexes for treatments and continuing limitations. These indexes were later tallied for each soil with the indexes for all mapping units being arrayed from high to low. This numerical array was divided into classes and an adjective rating (Table 2-2) of soil potential assigned to each soil. Reaction of the conference participants was favorable to the concept of soil

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[4]Personal communication with David F. Slusher, Assistant Director of Soil Survey Interpretations Division, Soil Conservation Service, Washington, D.C. on March 4, 1977.

potential and the draft procedures developed by the Task Force to arrive at these ratings. By working through the ratings of these different soils valuable experience was gained with the soil potential concept. The results along with suggestions and ideas from the ensuing discussions at the conference were considered by the Task Force committee in writing their draft report.

Guidelines For Preparing the Ratings

In June 1977, the draft guides for preparing soil potential ratings were finally published and circulated among SCS and cooperating agency staff (SCS, USDA, 1977). These underwent thorough interdisciplinary review and comment over the next year. The final guide for preparing soil potential ratings was published in April 1978 (SCS, USDA, 1978) incorporating many of the comments received from these individuals and organizations.[5] A brief discussion of the pertinent components of this guide follows.

The first section of the guide (Section 404, Part I) sets forth the policy of the Soil Conservation Service with reference to the preparation and use of soil potential ratings. These are considered as supplements to conventional soil survey interpretations[6] in interim soil reports, watershed workplans, soil handbooks, technical guides, and also included optionally in published soil

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[5] National Soils Handbook, Notice 31; Section 404, "Soil Potential Ratings," April 21, 1978.

[6] This group includes land capability classes, woodland suitability groups, range sites, soil limitations, or soil management groups.

Table 2-2. Soil potential for septic tank filter fields of selected soils in Tennessee.

Soil	Limitations and Restrictions	Potential and Treatment	Continuing Limitations
Jefferson gravelly loam 5 to 12 percent slopes	None	Excellent: Conventional system 190 sq. ft./bedroom	None
Memphis silt loam 2 to 6 percent slopes	None	Good: Conventional system, 300 sq. ft./bedroom	None
Memphis silt loam 12 to 20 percent slopes	Moderate: Slope	Good: Conventional system, slope design, 300 sq. ft./bedroom	None
Linsdale silt loam 0 to 2 percent slopes	Severe: Wetness	Good: Conventional system, areawide subsurface drainage, 250 sq. ft./bedroom	Maintain drainage system
Grenada silt loam 0 to 2 percent slopes	Severe: Percs slowly Wetness	Fair: Conventional system, alternate valve, 360 sq. ft./bedroom	Occasional surface drainage

Table 2-2. Continued.

	Limitations and Restrictions	Potential and Treatment	Continuing Limitations
Waverly silt loam 0 to 2 percent slopes	Severe: Wetness	Poor: Mound system	None
Talbott silt loam 8 to 12 percent slopes	Severe: Percs slowly Depth to rock	Poor: Mound system	None
Memphis silt loam 25 to 30 percent slopes	Severe: Slope	Very poor: No known system	

SOURCE: Personnel communication with David F. Slusher, Assistant Director of Soil Survey Interpretations Division, Soil Conservation Service, Washington, D.C. on March 4, 1977.

surveys. The policy statement encourages preparation of these ratings with interdisciplinary assistance from technical experts outside the SCS to supplement their expertise. Ratings must be made for soil map units by a systematic procedure although components of multitaxa map units may be evaluated separately to supplement the overall rating of the soil map unit. The policy statement also emphasizes that criteria used to prepare these ratings be agreed upon locally rather than using nationwide criteria. Hence, these ratings may be different in nearby areas, counties, states, or regions.

The second part of the guide (Section 404, Part II) is a brief outline of the systematic procedures used in preparing soil potential ratings for documents published by the SCS. These identify the following information:

(i) measures and their costs for overcoming soil limitations;

(ii) the performance level of the soils; and

(iii) limitations continuing after corrective measures have been applied.

A "soil potential index" is calculated by tallying together the indexes of these three components. This numerical rating is used to determine the soils relative suitability or potential among all soils in an area for a given land use. The soil potential index (SPI) is expressed by the general equation:

$$SPI = P - (CM + CL)$$

where P = index of performance or yield as a locally established standard

CM = index of costs of corrective measures to overcome or minimize the effects of soil limitations

CL = index of costs resulting from continuing limitations

The "P" component of this equation is an index of a performance or yield standard which is established and defined locally (Section 404.5a). This may be measured in terms of tons, bushels, cubic feet, or other yield levels for agricultural land uses. The actual yield or performance of each soil is then compared against this local standard. Soils with above average performance levels will have their SPI increased by the amount the yield exceeds the standard. Soils with substandard yields or performance will have their SPI decreased by the amount the yield is below the standard. In the case of primarily nonagricultural land uses where performance is not measured in tons, bushels, or other yield levels, P may be arbitrarily set at 100 or another convenient index value.

The "CM" component of the equation is an index of added costs above a defined standard treatment or management system that is commonly used if there are no soil limitations that need to be overcome (Section 404.5b). Soils with no soil limitations, therefore, would have a CM value of zero with no corresponding decrease in the overall SPI value. The guide emphasizes that local experts are needed to help furnish this information on these kinds of corrective measures or workable options needed, their costs, and effectiveness. Technical guides, soil handbooks, and research data published by the National Cooperative Soil Survey are also useful references for this type of information. For soils used extensively for the purpose being evaluated, the required corrective measures may be well known. However, for soils not now used for the land use being evaluated, corrective measures may need to be inferred from performances on similar soils in the local area for these purposes.

The "CL" component of the equation is an index of costs resulting from limitations continuing after corrective measures have been applied. These may have adverse effects on either social, economic, or environmental values. As defined in the guide (Section 404.5c), there may be three general types of continuing limitations:

(i) performance such as low yields, inconvenience, discomfort, probability of periodic failure, limitations resulting from the size, shape, or accessibility of an area, or associated soils that restrict a soils use or use periods;

(ii) annual or periodic maintenance costs such as pumping to remove excess water, irrigation, maintenance of drainage or terrace systems, or pumping and removal of septic tank wastes; and

(iii) off site damages from sediment or other forms of pollution.

A worksheet is required to systematically record the information obtained for the components of this equation (P, CM, and CL). Table 2-3 is an example of one such worksheet provided as an illustration in the guide (Exhibit 404.6 [a]). As a first step for

Table 2-3. Worksheet for preparing soil potential ratings.

Soil Use: Area:

Mapping Unit:

Evaluation Factors	Soil and Site Conditions	Degree of Limitation	Effects on Use	Corrective Measures Kinds	Corrective Measures Index	Continuing Limitations Kind	Continuing Limitations Index

Performance Standard Index	Measure Cost Index	Continuing Limitation Cost Index	=	Soil Potential Index

SOURCE: SCS, USDA, 1978, Exhibit 404.6(a).

completing this worksheet, the guide requires that the soil use be defined, local performance standard established, and evaluation criteria prepared (Section 404.6[b]). This definition must list the specific conditions under which the ratings apply. For many land uses this may require some assumption of the density of use, basic management system, or kind or size of equipment used. The evaluation criteria selected includes the soil, site, and other nonsoil features that affect the use. The soil factors considered for some land uses may be selected from guides used in rating mapping units by degree of limitations (National Soils Handbook, Section 403).

Table 2-4 is an example of a completed worksheet which has been provided in the guide as a model illustration (Exhibit 404.6[c] [1], No. 3). Calloway silt loam has been rated, in this case, for dwellings without basements in Alpha County. For this use, the four selected evaluation factors, their class ranges, and limitation ratings have been entered on the worksheet. The effects of these factors on soil use and corrective measures to overcome or minimize soil limitations are noted, as well as limitations continuing after these measures have been applied. The costs of these corrective measures and continuing limitations are expressed in units of the same scale which may be initial installation or annual costs. In this example, these index values are a percentage of the estimated costs. Finally, the index values for corrective measures (CM) and continuing limitations (CL) are

Table 2-4. Example of completed worksheet for preparing soil potential ratings.

Soil Use: Dwellings without basements — Area: Alpha County

Mapping Unit: Calloway silt loam

Evaluation Factors	Soil and Site Conditions	Degree of Limitation	Effects On Use	Corrective Measures Kinds	Corrective Measures Index	Continuing Limitations Kind	Continuing Limitations Index
Depth to high water table	1-2.5 (Perched)	Severe	Wet lawns Construction problems	Surface drainage Special drainage during construction	1 4	Maintain drainage	1
Flooding	None	Slight	None				
Slope	0.5-2%	Slight	None				
Shrink-swell	Moderate	Moderate	Foundation failure	Deepen and strengthen footings			
				Total	9	Total	1

$$\underset{\text{Performance Standard Index}}{100} - \underset{\text{Measure Index}}{9} - \underset{\text{Continuing Limitation Index}}{1} = \underset{\text{Soil Potential Index}}{90}$$

SOURCE: SCS, USDA, 1978, Exhibit 404.6 (c) (1) No. 3.2.

summed for deduction from the performance standard index (P) to determine the soil potential index (SPI). The value of 90 obtained in this example is used to help array this mapping unit according to its soil potential for dwellings without basements in Alpha County.

Since publishing this guide in April 1978, the SCS has undertaken several pilot projects to help familiarize state and regional personnel of the National Cooperative Soil Survey with its general methods and procedures for preparing ratings of soil potential. One completed project in southwestern Oregon has dealt with pear production; another in Leon County, Florida with septic tank filter fields. Work continues in other areas in the United States to gain experience at the local and regional level and to help recommend changes in the national guidelines where needed.[7]

Computerized Soil Maps

The use of computers to assist in the analysis of soil survey data is a fairly recent development, as is their application to the production of maps, tables, and other graphic displays. The need for computer processing techniques became evident to many in the National Cooperative Soil Survey about 1960 (Swanson, 1970). With the introduction of more precise quantitative field descriptions and laboratory determinations of soil characteristics, the annual accumulation of research data was beginning to tax the

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[7]Personal communication with Donald E. McCormack, Director of Soil Survey Interpretations Division, Soil Conservation Service, Washington, D.C. on December 4, 1978.

capacity of existing manual data-handling techniques to efficiently store and process these new data. Coincident with this mushrooming data-handling problem was an increasing public awareness and appreciation of environmental quality concerns. Data on soil resources became extremely valuable tools for examining the relationship between man and the land, but the response time for providing suitable data was correspondingly shortened.

Responding to this challenge, soil scientists during the early 1960's looked to automatic data processing to allow more efficient handling of their data. These were primarily at first small-scale experiments, and it was not until the later part of the decade that concerted efforts were well underway to expand the use of these new automated techniques (Swanson, 1970). These efforts were truly international in scope with programs underway in Australia, Belgium, Canada, France, The Netherlands, and the United States. Reviewing these systems, Bie and Schelling (1975) observed that most had an automated cartographic component permitting areal display of their stored data bases.

Interpretive soil maps have been prepared manually from information contained within the soil survey, as well as from other resource inventories (Bauer, 1966). These maps have proved extremely useful for most user groups, although until recently their numbers were severely limited because of the difficulties and expense involved, especially if different source maps needed to be converted to a common scale or if the interpretive requirements were complex. The lack of interpretive soil maps has been one of the greatest restrictions to the use of soil surveys by resource planners (Hunter, Tipps, and Coover, 1966). Johnson (1975) sees the application of automated cartographic systems, joined with other automated systems for soil survey interpretations, as one way to "cut the cost of preparing interpretive resource maps and make them available to a great variety of users."

Grid-Based Encoding of Soil Maps

Nichols and Bartelli (1972) presented one of the first attempts to apply automated cartography to soil mapping. They adapted the Map Information Assembly and Display System, abbreviated MIADS (Amidon, 1966), to help produce interpretive soils maps for 451,200 acres in Oklahoma County, Oklahoma. A grid of 40 acres per cell was superimposed over the detailed soil map sheets and the dominant kind of soil (covering at least 40 percent) in each cell was recorded for storage in the computer. The interpretive maps were generated by the MIADS program which translated the dominant soil in each cell to a rating and output this result on unlined paper using the computer's high-speed line printer. These final copies were put together with transparent tape to make a visual display for the entire county. Map scale was corrected through photographic reproduction. Place orientation for map readers was enhanced with a plastic overlay showing roads, streams, towns, and other cultural features.

Nichols (1975) examined the characteristics of the computerized soil maps produced using the MIADS program. Nichols and

Bartelli (1972) termed these "in between maps" since the amount of detail furnished is intermediate between that presented by the detailed soil map and that presented by the general soil map published in county soil surveys. The authors made a study of the agreement between detailed soil maps and those which are computer-generated using different cell sizes. The results indicated that the average agreement for maps with a medium amount of cartographic detail was 70.5, 64.4, and 48.4 percent for cell sizes of 21.33, 40, and 160 acres, respectively. On maps with low, medium, and high amounts of cartographic detail, the average agreement was 71.6, 64.4, and 41.3 percent, respectively, for a cell size of 40 acres. These data reveal the importance of cell size and cartographic detail on the potential degree of change that can be expected in computerized soil maps relative to the actual map.

A comparison was also made of the acreage of soil mapping units obtained from the MIADS program versus those reported in published soil surveys. The MIADS program can be used to produce measurement data by multiplying the cell size by the frequency of cell occurrence. A t test was used to examine the differences between the two sample means. This statistical test showed no significant difference in sample means for any of the mapping units at a 95 percent probability level. Nichols concluded that the tabular data obtained from the MIADS program can be effectively used in broad planning of large areas, such as townships, counties, and regions.

The digitizing process used in MIADS to convert the detailed soils map to a set of records completely readable by a computer has been widely practiced and is one of the most popular techniques to encode soils maps. Tilmann (1977) has called this grid-based procedure the "most straightforward method to computerize (geocode) a soils map." The procedure is relatively inexpensive since elaborate and costly machinery are usually not required and data encoders can be quickly trained (Calkins and Tomlinson, 1977). Although such arbitrary grid-cell encoding may involve a considerable loss of soils information, many investigators have balanced this loss of information with the relatively higher costs of utilizing more elaborate polygon-encoding techniques, if available, particularly, if there exists a large volume of data. Investigators have modified this grid-based technique to minimize losses of information without their having to resort to more costly graphic encoding options. A brief literature review illustrating the most relevent of these research projects follows.

Relatively large-sized cells have been used for encoding soils data for statewide resource inventories. Generalized soils information was entered into the Land Use and Natural Resource Inventory of New York, abbreviated LUNR (New York State Office of Planning Services, 1971), from a general soil association map of New York State. The scale of this map was 1;250,000 and the minimum mapping unit size was approximately 300 acres. Data were encoded using the one-square kilometer cell size (247.1 acres) of the LUNR inventory entering only the dominant soil associated within each of these cells. Similar procedures were used for encoding soils data into the Minnesota Land Management Information System, abbreviated MLMIS (Anderson, 1976). Scale of the generalized soil association map was 1:250,000 with the smallest unit delineation being approximately 600 acres. Cell size used for encoding was 40 acres. Both state systems utilize automated cartography to output high-speed, line-printer maps.

Regional and county-wide projects have used much smaller cell sizes for encoding soils data. The study made by Hitchcock, et al. (1975) of Knox County, Tennessee is a fairly typical one. In this particular case, soil map data was digitized from a county soil survey using a grid-cell size of 2.68 acres (3.75 seconds on a side). Each cell was geodetically registered and a mylar-grid overlay was computer-drawn to compensate for cell size variation with latitude changes. The soil map unit recorded for each cell was the unit at the exact center of the cell. These data were supplied to the GRID mapping program (Sinton and Steinitz, 1971) to produce single-factor analysis maps on the computer lineprinter. Hepner (1977) also used similar procedures to encode soils data using a cell size of 4.25 acres for a 4,853 acre area in Schuylkill County, Pennsylvania. The West Michigan Regional Planning Commission developed a natural resource information system, encoding soil maps for their region using a grid cell size of 10 acres (Stockman, 1977). They had been assisted by Michigan State University staff of the Project for the Use of Remote Sensing in Land Use Policy Formulation who had previously used this same 10-acre cell size for encoding a soil map for Windsor Township, Eaton County, Michigan (Remote Sensing Project, M.S.U., 1976).

Experimentation with Computer Display Devices

The standard line printer referred to in many of these studies works on a fixed grid, usually with a line spacing of 0.10 inch and a character interval of 0.125 inch, thus each character printed occupies a rectangular space. Hence, computerized soil maps produced by these devices would not be true to scale on both the X and Y axes since the map will be stretched in the north-south direction. Ragg (1972) solved this problem by using a modified IBM line printer to produce square characters for a computer-generated soils map. These devices, however, are rarely available at many computer installations, hence computer map distortion is a common problem. Jansen and Fenton (1978) recommended procedures for generating computer soils maps which will help preserve the detail of soil survey base maps. They reported that cells used for encoding data had to be smaller than the smallest delineation on the source maps to preserve the approximate shapes and continuity of these delineations. Their research indicated that a 0.5-acre grid size was adequate to fulfill this function for a base map at a scale of 1:15, 840. A slightly larger cell size (2 acres), in their opinion, had given poor reproduction for this same map scale, although it might suffice for a less detailed map.

Because of the inherent problems of computer map distortion using the line printer, several researchers have turned to the computer plotter (e.g., drum or flat-bed) for displaying soil survey data. Cox (1977) reported that by using the computer plotter he was better able to produce interpretive soils maps at a scale comparable to the original base maps without having the resort to cartographic or photographic techniques. These devices can also offer a wider range of mapping characters, drafting papers, pen sizes, and ink colors (Calkins and Tomlinson, 1977). Although plotter maps are relatively more expensive than those printed on lineprinters, they are also higher quality map products which reproduce extremely well for publication. Tilmann, Enslin, and Hill-Rowly (1977) reported that interpretive soils maps for Windsor Township, Eaton County, Michigan were produced primarily on the computer-plotter because the maps were to be reproduced and used in formal presentations. The PLOTTERMAP phase of the Resource Analysis Program, abbreviated RAP (Tilmann, 1978), was used to direct the pen-and-ink plotter to draw different types of discrete symbols in each cell of the display map. A grey-tone or shading effect was developed in several plotter maps using concentric octagons arranged to represent density shading. Nominal data, such as soil type, were represented on other maps by alphabetic characters, with line boundaries drawn around contiguous cells.

Modifications to Grid-Based Encoding

As a result of recent investigations and spectacular advances made in automated cartography, it has become possible to create on computer soil maps approximate boundaries corresponding to the original soil boundaries on the detailed soil map. The type of computer hardware required and techniques for data encoding vary greatly among the different systems in existence, but the investment needed usually remains relatively high. Also, as Bie and Schelling (1975) point out, various technical problems remain before these experimental systems can be adopted by many planning and research agencies.

Researchers have attempted to modify the grid-based encoding technique to reconstruct the original boundaries on the soil map. Meyers, Durfee, and Tucker (1974) worked with an interdisciplinary team of computer scientists, planners, and soil scientists, at Oak Ridge National Laboratory to develop procedures for digitizing and displaying soil survey data on a plotter. These procedures were designed for use with soil scientists's field sheets or existing published soil maps. To illustrate this technique in Tennissee, a dot grid of 1.18 acres in size was drawn on a sheet of mylar, consisting of a series of points representing the four corners of each cell on the grid. By connecting the nearest lattice dots, approximate boundaries were formed corresponding to the original soil boundaries on the field sheet or published survey. An identifying soil number was placed within each soil polygon. The boundaries and the soil number were manually digitized for storage in the computer. These data were then used by a plotter to generate soils maps or interpretive maps.

Since 1970, some very interesting work on computer mapping has also been done by an interdisciplinary team of researchers at the University of Massachusetts (Fabos, et al., 1973; Ferris and Fabos, 1974; Fabos and Caswell, 1977). During these years they have been developing a parametric landscape assessment model, named METLAND, which could help evaluate the consequences of metropolitanization on landscape resources, such as water, agricultural productivity, wildlife productivity, sand and gravel supply, and visual landscape quality. As part of this research effort, studies were undertaken to select a computer manipulating and mapping system to be used in the landscape planning model. The researchers modified an existing software package, named COMLUP (Allen, 1973), which was originally developed by the U.S. Forest Service. Data are input to this package in the form of digitized x-y coordinates of points in each line segment (soil boundary) on the map, with identifiers to the right and left of the line specified. These identifiers can be used to aggregate polygons by eliminating line segments separating them. The program includes subroutines at this stage to edit the digitized data for various type of coding errors and facilitate their correction. After this testing phase, COMLUP internally converts the digitized coordinates into points on a matrix by superimposing a grid with 500,000 cells

(500 x 1,000). These data points are then reconverted to line format so that they can be output on a Calcomp plotter in polygon form or on the line printer in grid format.

Automatic scanner digitizers have been adapted by a number of researchers in order to speed up soil map production. A research team at Northeastern Illinois Planning Commission, in conjunction with Argonne National Laboratory, have developed an experimental optical-scanner system interfaced with a computer for rapidly encoding soil maps (Northeastern Illinois Planning Commission, 1977). This system was modified from an image processing machine used in fingerprint recognition to distinguish boundaries on soil maps. Briefly, the system consists of a cathode-ray tube as a light source, photocell sensors, and a photomultiplier which registers the small dots of points and lines on the scanned map. This scanner can encode nearly 80 acres of map area in three minutes. When these dots are assembled together and printed out they form lines which delineate the approximate soil boundaries on the original base map. Computer software programs, especially written for this system, can be used to calculate acreage for the encoded soil mapping units. Another computer software program, DISSPLA, is used to command a Calcomp 936 plotter to generate interpretive soil maps. These researchers believe that it is conceivable that other mapped data, such as geologic, vegetation, or land use, may be digitized and stored for analysis and cross analysis. More importantly, however, this system offers the advantage of getting current soil survey maps into a useable form to planners as quickly as possible.

The Advanced Mapping System (AMS) is being prepared by the Soil Conservation Service (SCS) of the U.S. Department of Agriculture to provide such a system. For a number of years, the SCS viewed this system only as a method to significantly reduce the amount of map finishing work in the publication of soil survey reports (Swanson, 1970; SCS, USDA, 1975b). In 1974, a Washington task force determined that states could do the compilation and finishing of soil maps, so the AMS was redesignated to reproduce film positives or negatives of base, topographic, soil, and interpretive maps ready for photographic and lithographic processing (Johnson, 1975). Soil maps from published surveys will be digitized, stored together with data previously entered in the National Soil Pedon Data Bank (Thompson, 1977), and then processed, analyzed, and retrieved as desired.

The AMS located at Hyattsville, Maryland, has been designed around four Hewlett-Packard 2,114 minicomputers and a Gerber Model 1,275 automatic drafting table. The system is made up of a scanning, identification, editing, and drafting subsystem. Each subsystem independently performs one or more operations.

The scanning subsystem automatically scans and digitizes map sheets with any type of lines, such as contours or map boundaries, at the rate of four square inches per second. Coordinate data for lines, symbols, and alphanumerics will be recorded for each sheet and transferred to the identification subsystem. All lines are stored as line segments with soil symbol identifiers on either side specified. Since character recognition is not yet part of the system, alphanumerics (soil symbols) have to be interactively entered in the data base to link line segments to soil symbols. These data are then passed onto the editing subsystem to produce a preliminary plot of the map. Correction of errors are then made on a graphic display screen (CRT's) and a magnetic tape produced for the automatic drafting machine. This device draws with a pen on paper or a beam of light to expose photographic films. Finished maps can be plotted at any scale with any line width desired. The cost for digitizing the soils map is estimated at $3,000. for an average county and then approximately $200. to $400 to produce each interpretive soils map.[8]

The recent arrival of powerful new computer technologies promises to change the way soil maps are digitized and this data displayed through interpretive maps. Rather than depending on centrally located computers, accessible only in large cities and universities, it may be available in retail stories. Yahner (1977) reports that Indiana is establishing a computer network of interactive terminals, called the FACTS system, in county extension offices across the state. These terminal packages will have disc storage and rapid printing facilities enabling local groups to

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[8]Personal communication from C. Gene Johnson, Chief, Map Construction Branch, Cartographic Unit, Soil Conservation Service, Washington, D.C. on January 21, 1977.

potentially store digitized soil maps and to generate interpretive maps. Already, a small number of researchers have developed computer software packages to store, manipulate, and display natural resource data on small computers or portable terminals. McCown, Butler, and Gates (1977) has written a computer software program, called GRASP, to operate a portable teletypewriter or graphic terminal connected to the computer by telephone. This system features use of simple English-like commands to simplify data entry, response time, editing and mapping procedures. Butler, McCown, and Gates (1977) used GRASP to generate line-printer maps on a portable computer terminal. Professor Peter Trowbridge and his associates at Cornell University have devised the Land Use Information Retrieval System (LUIRS) for use on small computers which store data on what is known as a floppy disc (Anonymous, 1978). They will be programmed for use by planners in small rural communities in New York, even if they have had no experience in computer programming. These and other innovative programs will grow in numbers and future importance as desk-top computers are adopted for use by many communities across America.

Summary

This chapter has discussed the historical development of the soil potential concept and the state-of-the-art in computer-drawn interpretive soil maps. Existing methods and techniques used to prepare soil potential ratings were presented and analyzed. The advantages and disadvantages of different map encoding and display techniques used for preparing computer-drawn interpretive soil maps were discussed.

CHAPTER III

RESEARCH METHODS AND PROCEDURES

The previous two chapters have served to precisely define the problem, state the objectives of the study, and review pertinent literature and work underway relevant to the problem. The purpose of this chapter is to describe the specific methods, techniques and tools employed to meet the objectives of this study. For the purpose of presentation, the chapter has been divided into three sections, namely, procedures used to generate ratings of soil potential, development of the computer masterfile and the data analysis process.

Preparation of Soil Potential Ratings

For the purposes of this study, soil potential is defined as the relative quality or suitability of a soil for a particular land use, using the most recent, acceptible technology, as compared to other soils in Eaton County. A systematic procedure was employed in this investigation to numerically rate a soil's potential for several different land uses in Eaton County, Michigan. In deriving this "soil potential index," consideration was given to the relative costs of applying feasible treatments or management practices to overcome soil limitations, and the limitations remaining after these corrective measures have been applied. The actual step-by-step procedures for preparing these soil potential ratings in the study area are described in the following pages.

Land Uses and Soil Properties

The first task for the investigator was to choose the land uses for which soil potential ratings would be prepared in the study. Those selected were the following: (1) septic tank filter fields for on-site waste disposal; (2) residential streets and roads; (3) residential dwellings with sanitary sewers and basements; (4) residential dwellings with sanitary sewers and without basements; and (5) excavations for residential waterlines. By selecting these five nonagricultural land uses the intention was to illustrate several different kinds of urban uses which have been closely identified with site considerations for residential home construction in the Lansing metropolitan area and which also have slightly different physical properties.

The next step was to develop an operational definition for each of these land uses and prepare rating criteria for their evaluation. The definitions were written to set forth for the reader the precise conditions and assumptions under which the soil potential ratings would apply. Evaluation guides were then developed for each land use listing the important soil, site and other factors affecting soil performance for the intended use. For the purposes of this study, these tables of criteria were modified, with the assist

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assistance of Delbert Mokma and Rodney Harner,[1] from existing guide sheets published in the National Soils Handbook (Section 403). The definition of these specific land uses and their evaluation guides are discussed in the sections which follow.

(1) Septic tank filter fields for on-site waste disposal.

These are subsurface systems of tile or perforated pipe that distribute sewage effluent from a septic tank into a soil for a single-family (three bedroom) dwelling. The system is expected to be appropriately designed to meet all local health department regulations and accommodate a peak flow of approximately 150 gallons per day per bedroom for a year-round residence without surfacing of effluent or pollution of ground water. The lot size for this three-bedroom residence is expected to be a minimum of 1/3 acre with public water supply or 1/2 acre with private water supply. These lot sizes will allow sufficient land to isolate the system from wells, boundaries, dwelling foundations or bodies of water, and also to provide sufficient land for potential replacement of absorption fields.

For disposal of septic tank effluent in seepage fields, criteria in Table 3-1 indicate the soil properties and site features that can affect selection, design, or application of treatment measures. Properties that affect absorption of sewage effluent are: the percolation rate, depth to water table or bedrock, and susceptibility to flooding. Rapidly and moderately permeable soils

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[1] Assistant Professor Department of Crop and Soil Science, Michigan State University and State Soil Scientist, Soil Conservation Service, U.S. Department of Agriculture, E. Lansing, Michigan.

(percolation rates faster than 60 min./in.) with high water tables (<40 in.) or rapidly permeable soils shallow (<40 in.) to bedrock pose significant problems because inadequate soil is available to purify sewage effluent before it reaches the water table or bedrock layer. Slowly permeable soils (percolation rates slower than 60 min./in.) also have poor filtration capabilities because infiltrating liquid waste is unable to rapidly percolate through the slowly permeable subsoil horizons. Flooding causes difficulties with these systems by increasing the hazards of pollution. To overcome some of these limitations, the sewage disposal system is often raised above the natural soil by using suitable fill materials. This increases significantly the volume of material available for sewage filtration.

Moderate slope (8-15%) is a soil property that makes installation and maintenance of septic tank filter fields more difficult. Steeper slopes cause difficulty in their layout and construction, as well as increasing the risk of soil erosion, lateral seepage, and surfacing of the effluent in downslope areas. Construction can be done on steep slopes, but careful design and maintenance is necessary.

(2) Residential roads and streets.

These are local roads and streets that have an all-weather asphalt pavement expected to carry up to 15 trucks and 500 cars per day serving the residential dwellings along the streets all year. Pavement width in these residential areas is commonly expected to be 30 feet with a minimum right-of-way of 66 feet. The full-depth asphalt pavement is also expected to consist of one or

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Table 3-1. Rating criteria for soil potential of septic tank filter-fields for on-site waste disposal.

Factors Affecting Use	Degree of Limitation		
	Slight	Moderate	Severe
Soil percolation rate (min./in.)	<45	45-60	>60
Seasonal high water table (depth in.)	>72	40-72	<40
Flooding	None	Rare	Common
Slope (percent)	0-8	8-15	>15
Depth to bedrock (in.)	>72	40-72	<40

more courses of hot-mixed bituminous material constructed on a prepared subgrade of the underlying local soil material, whether cut or fill. These roads are graded to shed water and conventional drainage measures are provided.

Table 3-2 lists the soil properties and site features that affect soil performance, require corrective measures, and create limitations for residential roads and streets. Properties that affect the traffic-supporting capacity of the subgrade are: depth to seasonal high water table, soil strength as inferred from the United Soil Classification, and potential frost-action. Sands and gravels (GW, GP, SW, SP, GM, GS, SM, and SC) retain a substantial amount of their load-supporting capacity when wet, but organic soils (Pt) and those having appreciable amounts of clay and fine silt (CH, OH) become quite soft and plastic when wet. Careful design

Table 3-2. Rating criteria for soil potential of residential roads and streets.

Factors Affecting Use	Degree of Limitation: Slight	Moderate	Severe
Seasonal high water table (depth in.)	>30	12-30	0-12
Flooding	None	Rare	Common
Slope (percent)	0-8	8-15	>15
Unified soil group classification	GW, GP, SW, SP, GM, GC, SM, SC	CL with PI[1] less than 15	CL with PI[1] more than 15, CH, MH, CH, OL, Pt
Potential frost action	Low	Moderate	High

[1]PI means plasticity index.

of the pavement structure is required to take into account this reduced supporting capacity of the subgrade during the frost-melt period. Soils high in organic matter are also unstable when dried because the organic matter will oxidize and cause subsidence of the roadbed. The entire depth of organic or frost-susceptible material may have to be removed and replaced by suitable fill.

The properties that affect the ease of excavation and grading are: susceptibility to flooding and slope. Flooding is a serious problem because roads are likely to be damaged to the extent that repairs are necessary. Grade heights may have to be established above seasonal flooding levels. Slope is also an important consideration because it affects the work involved in roadway construction. Roads and streets can be built more easily on the soils with gentler slopes. Steeper slopes involve more cutting and filling of soil material and increasing hazards of erosion.

(3) Residential dwellings with sanitary sewers and basements.

These are single-family residences of not more than three stories high, located on 1/2 to 1/2 acre lots. The typical foundation is assumed to be a spread concrete design of approximately 1,500 square feet built at a depth of 7 feet and fully waterproofed. The life span for these dwellings is expected to be more than 50 years and their design fully acceptable under the FHA Minimum Property Standards for One- and Two-Family Dwellings (FHA, HUD, 1973). The ratings for this land use assume adequate sewage disposal by sanitary sewers and intensive use of the yard, lawn, garden, and play areas. The soil properties and site features considered (Table 3-3) are those that affect excavation and construction costs and landscaping.

The properties affecting excavation and construction costs of the basement foundation are: depth to seasonally high water table, depth to bedrock, susceptibility to flooding, slope, and subsurface soil texture. Foundations built on soils with high water tables and in flood-susceptible locations are likely to have wet basements unless they are waterproofed and reinforced to withstand hydrostatic pressures. Hard bedrock and organic materials

Table 3-3. Rating criteria for soil potential of residential dwellings with sanitary sewers and basements.

Factors Affecting Use	Degree of Limitation		
	Slight	Moderate	Severe
Seasonal high water table (in.)	>72	30-72	0-30
Depth to bedrock (in.)	>60	40-60	<40
Flooding	None	Rare	Common
Slope (percent)	0-8	8-15	>15
Unified soil group (20-60 in.)	--	--	Pt

also causes difficulties, especially if it is near the surface and must be excavated or blasted. Slope is another property that can cause difficulties in foundation excavation. Cuts and fills may be required on steeper slopes to provide level surfaces for building sites.

The property affecting the landscaping of the dwelling site is the depth to seasonally high water table. High water tables reduce plant rooting depth and also restrict intensive use of yards and gardens. Subsurface drainage may be required to alleviate this problem if the soil is permeable enough for excess water to move through the soil into the drain tile.

(4) Residential dwellings with sanitary sewers and without basements.

These are single-family residences of not more than three stories high located on 1/3 to 1/2 acre lots. The typical foundation of 1,500 square foot is assumed to have spread concrete footings and a slab-on-grade construction. The lifespan for these dwellings is expected to be more than 50 years and their design fully acceptable under the FHA Minimum Property Standards for One- and Two-Family Dwellings (FHA, HUD, 1973). The rating for this land use assumes adequate sewage disposal by sanitary sewers and intensive use of the yard, lawn, garden, and play areas.

The soil properties and site features discussed for residential dwellings with basements (Table 3-3) are similar to those influencing the ratings for residential dwellings without basements (Table 3-4). The exceptions are: (1) the addition of soil strength as inferred from the Unified Soil Classification, and (2) the changing of the limitation rating of seasonally high water tables. Soil strength is a factor that affects the design of the foundation slab. Gravels (GM, GP) or sandy soils with or without silts and clay (GM, GC, SW, SP, SM and SC) and silts (ML, MH) provide the best support for a slab foundation on grade. Those laid on other soils (CL, OL, CH and OH) require reinforcement to resist the differential movement of the soil. Soils high in organic matter (Pt) are not stable enough for the support of ground-supported slabs and are commonly removed from the site. High water tables also pose serious problems for construction of these foundations and drains may be required to control water movement under the slab.

(5) Excavations for residential waterlines.

These are trenches or holes dug in the soil by trenching machines or backhoes below the greatest recorded frost penetration in the study area (60 inches) to install residential waterlines. The trench is expected to be about 2 feet wide and 5 feet deep or deeper for the pipe to be below frost penetration. Fire hydrants are also expected to be connected to these mains every 500 feet with provisions for shut-off valves every 800 feet on residential roads and streets.

Table 3-4. Rating criteria for soil potential of residential dwellings with sanitary sewers and without basements.

	Degree of Limitation		
Factors Affecting Use	Slight	Moderate	Severe
Seasonally high water table (in.)	>30	18-30	0-18
Depth to bedrock (depth in.)	>60	40-60	<40
Flooding	None	Rare	Common
Slope (percent)	0-8	8-15	>15
Unified soil group[1]	GM, GP GC, SW, SP, SM, SC	CL, ML, MH	CL, OH, CH, OH, Pt

[1]Thickest layer between 10 and 40 inches.

Table 3-5 lists the soil properties and site features that affect soil performance, require corrective measures, and create

Table 3-5. Rating criteria for soil potential of excavations for residential waterlines.

Factors Affecting Use	Degree of Limitation		
	Slight	Moderate	Severe
Seasonal high water table (in.)	>72	30-72	0-30
Depth to bedrock (in.)	>60	40-60	<40
Flooding	None	Rare	Common
Slope (percent)	0-8	8-15	>15
Unified soil classification (20-60")	--	--	Pt
Corrosivity	Low	Moderate	High

limitations for residential waterlines. Properties that affect the ease of excavation and construction costs are: depth to seasonal high water table, depth to bedrock, susceptibility to flooding, slope, and the Unified soil group texture. High water table and flooding may restrict the time that the excavation can be made. Dewatering of the trench may be required in serious cases before the pipe can be laid. Hard bedrock and organic soils also cause difficulties, especially if they are near the surface and must be excavated or blasted. Backfill must be imported to replace these materials. Slope is a property that can cause difficulties in the use of backhoes and digging machines necessitating the use of manual techniques to lay the waterlines.

Risk of corrosion is a factor that pertains to the potential soil-induced chemical action of the soil weakening uncoated metal pipes. High risk soils may require protective measures for waterlines to help avoid or minimize damage resulting from the corrosion.

Data Collection

Once the land uses were defined and evaluation criteria prepared for each, the next task was to assemble data on local corrective measures to overcome the specific soil limitations, if any, their relative costs, and limitations that continue after these treatments are applied. A systematic plan was developed at this stage for collecting these data on local conditions existing in Eaton County, Michigan. The actual design of this data collection procedure is described in a step-by-step format below.

(1) Identify technical experts to provide data.

The first task was to identify key individuals and organizations that could provide information on the kinds of corrective measures needed on soils in the study area, the relative costs or difficulties involved in overcoming these soil hazards, and the problems existing after these practices are installed. A listing of important building contractors and professional construction trade organizations in the Lansing metropolitan area was assembled with the assistance of several Michigan State University faculty members from the Departments of Agricultural Engineering, Civil and Sanitary Engineering, Crop and Soil Science, and Resource Development, as well as Cooperative Extension Service personnel in the immediate area. The telephone numbers of the initial contact for those organizations or individuals on this list was obtained by consulting the appropriate phone directory for that address in the Michigan State Library collection of current telephone books. (2) Compile list of corrective measures.

The individuals and organizations on this list were then contacted by phone to arrange meetings or conferences with their staffs. At the outset of each meeting, a brief description of the research was provided. The investigator reviewed the need for soil potential ratings, their basic concepts and present status of development, the interdisciplinary needs, and the requirement for local input to meet the needs at a county or subcounty area. The overall role of Michigan State University and the Michigan Agricultural Experiment Station was stressed to demonstrate the noncommercial motives of the study. The prospective benefit to local contrwctors of the results of this research was also emphasized to additionally induce their cooperation. Conversations with offices of professional trade organizations usually resulted in referrals to member contractors judged by the initial contact to be well-informed about the use of soils information on construction design.

Those interviewed were asked to describe the general construction designs they typically used and which they believed would overcome certain soil limitations. For example, home builders were asked how they compensated for hydrostatic pressure caused by high water tables in their construction of basement walls, or what engineering practice was used to prevent leakage in basements.

During the course of the interviews a list was then compiled (Table 3-6) of specific corrective measures used in the study area to overcome certain soil limitations for each land use.

(3) Compute costs for corrective measures.

The next task was to determine the relative costs of applying these corrective measures in the study area. Local building contractors and staff members of professional organizations assisted by making available actual case illustrations from their files with cost analyses where these corrective measures had been applied. The pricing information used in these projects, however, was not standardized since many projects had been undertaken in different years. The prices for these measures then had to be adjusted upward for rising material and labor costs existing in the Lansing metropolitan area at the time of this writing.

Appendix B contains the adjusted average unit costs of materials and labor used in these corrective measures for the different land uses in Eaton County, Michigan. These data were obtained from a number of standard reference texts commonly used in the construction industry for making up engineering estimates. The prices listed were obtained from actual job costs in 1978 and material dealers 1979 quotations for major cities in the United States. These were adjusted for material and labor costs existing in the Lansing metropolitan area at mid-year 1978. The items in these tables also include adjustments from contractors' and subcontractors' overhead and profit estimated at 30 percent.

Table 3-6. Soil limitations and corrective measures used for land uses in Eaton County, Michigan.

		Land Use				
Limitations	Specific Corrective Measures	On-Site Waste Disposal	Roads and Streets	Dwellings with Basements	Dwellings with-out Basements	Residential Waterlines
Corrosivity	Wrap pipe					X
Depth to rock	Excavate rock			X		X
	Sand mound	X				
Excess humus	Excavate peat and muck		X	X	X	X
Floods	Add fill to raise grade		X	X	X	
	Waterproof basement			X		
Low strength	Increase pavement thickness		X			
	Reinforce slab				X	
Percs slowly	Increase filter field size	X				
	Sand mound	X				
Wetness	Waterproof basements			X		
	Areawide surface drainage			X	X	
	Add fill to raise grade		X	X	X	
	Drainage of footing			X	X	
	Drainage of slab			X	X	
	Dewater trench					X
	Serial distribution	X				
Steep slope	Cuts and fills		X	X	X	
	Tamp backfill by hand					X
	Thrust blocking and anchoring					X

NOTE: An X indicates that the corrective measure is used for the specified land use.

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These adjusted costs (Appendix B) were then substituted back into the cost analyses for the corrective measures provided by the local contractors and trade association staff. Appendix C is then a summary of the corrective measures likely to be needed and their costs at mid-year 1978 for the selected five land uses in Eaton County, Michigan. These costs have been rounded to make them easier to use and still maintain adequate precision of the results. The range in study results is reported in these five tables.

(4) Determine continuing limitations.

Although corrective measures are applied to overcome soil limitations some limitations may remain and have adverse effects on social, economic, and environmental values. The next task in this study was to identify these continuing limitations and then assign a qualitative rating, employing the terms slight, moderate, or severe, to indicate the severity of these remaining limitations. A brief discussion of the procedure used to collect these data follows below.

Continuing limitations have been classified in the National Soils Handbook (Section 404.5c) into three general groups. The first group consists of those causing inconvenience or discomfort to a land user perhaps by the periodic failure of a corrective measure, such as a septic tank field. The second group contains those limitations that require increased expenditure for maintenance of these corrective systems. These are clearly economic since they affect returns and profits. The last group of continuing limitations contains those which result in off-site damages to the environment either by pollution of the air or water.

Table 3-7 was developed in order to rate these three different types of continuing limitations signifying not only the degree to which soil hazards have been corrected or overcome by special construction designs or treatment, but also, in general terms, a prediction of the cost and level of maintenance required for upkeep of these special treatments. A rating of slight means that good performance and low maintenance of the corrective measure can be expected. A rating of moderate means that one or more factors indicate somewhat less desirable performance and increased maintenance can be expected. A rating of severe means that poor performance and high maintenance can be expected. Assignment of these qualitative ratings to each continuing limitation was then made with the assistance of the technical experts.

Recording Data for Computer Input

A worksheet was developed for recording the critical data needed for generating the soil potential ratings by computer for the selected land uses in Eaton County, Michigan (Figure 3-1). Separate sheets were used for each soil mapped in Eaton County (45) and for each land use (5) in this study. The step-by-step process used for completing each numbered component of this worksheet is described below.

Table 3-7. Guide for preparing ratings of continuing limitations.

General Groups of Factors	Factors Affecting Use	Degree of Limitation		
		Slight	Moderate	Severe
Group 1	Ease or convenience in maintenance of system	Good	Fair	Poor
Group 2	Annual or periodic maintenance cost for system	Low	Moderate	High
Group 2	Probability of periodic failure of system	Low	Moderate	High
Group 3	Probability of off site changes to the environment	Low	Moderate	High

1. Map Unit--The name of the map unit was entered on each sheet whether it be a multitaxa or single taxon unit. Each component of a soil complex was rated on separate worksheets. The final rating of the entire unit was determined by multiplying the rating of each component by its estimated areal extent in the map unit and tallying these index values.

2. Evaluation Factors--The evaluation factors for each land use (Tables 3-1 to 3-5) were entered on the worksheet.

3. Soil and Site Conditions--For each soil map unit, the class or range of each soil property used as an evaluation factor was determined from the Eaton County Soil Survey (Feenstra, et al., 1978).

4. Degree of Limitation--The coordinated limitation ratings for each evaluation factor were recorded from the soil interpretations record (SCS-Soils-5).

5. Effects on Use--The nature of the factors rated with moderate or severe limitations on land use were recorded. These indicated the major effects that required coorective measures.

6. Corrective Measures--The kinds of corrective measures needed to overcome or minimize one or more soil

LAND USE: ______________________ AREA: ______________________

1 MAPPING UNIT: ______________________ SOIL MANAGEMENT GROUP: ______________________

2 EVALUATION FACTORS	3 SOIL AND SITE CONDITIONS	4 DEGREE OF LIMITATION	5 EFFECTS ON USE	6 CORRECTIVE MEASURES		7 CONTINUING LIMITATIONS	
				KINDS	COST ($)	KINDS	RATING
			8	TOTAL	$	TOTAL	

Figure 3-1.--Worksheet for recording data for preparing ratings of soil potential.

limitations were recorded for each soil with the assistance of the technical experts.

7. Continuing Limitations--Continuing limitations which are associated with each corrective measure were recorded as key phrases with the assistance of the technical experts. The qualitative ratings for each were entered as a numeric code (i.e., 1 = slight, 2 = moderate, 3 = severe in the appropriate column.

8. Totals--The costs for the corrective measures were then summed and the most restrictive rating for the continuing limitations were entered in the appropriate column. These two numeric values were interactively entered on a computer disk file for each soil and land use in the study.

Generating Soil Potential Indices

Following this data recording process described above, the next step was to use a statistical technique to calculate a "soil potential index" that would indicate each soil's relative suitability or quality for a given land use in the study area. This numerical index was derived from the cost of corrective measures used to overcome soil hazards and the ratings established for continuing limitations. These index values were subsequently used to assign each soil to a qualitative rating class indicating its relative potential for a particular use compared with that of other soils in the area. The multivariate statistical technique used to generate these numerical indices is called multidimensional scaling, and the remaining portion of this section will be devoted to a brief description of this technique.

Multidimensional scaling is a multivariate statistical technique that was originally developed by behavioral scientists for comparing the similarity between sets of objects (Golledge and Rushton, 1972; Tilmann, 1976). Each object can be thought of as existing in n-dimensional space, where n represents the number of attributes under examination. The numerical values of each attribute can be interpreted as a geometrical coordinate or projection on an orthogoral axes which, when used in conjunction with those of the other attributes, determines the location of the object or point in this n-dimensional space. The attribute may be measured on either the ordinal, interval or ratio scale since it is not necessary in multidimensional scaling to have metric information. Each attribute can be weighted to indicate its relative importance in defining the object. The Euclidean distance between that point and another located in this n-dimensional space is then the measure of the similarity between an object's attributes relative to the other object. This interpoint distance, d_i, between the i^{th} point with attribute set, Fn, of weighted importance, W_n, and another attribute set, O_n, is given as follows:

$$d_i = [\Sigma W_n (F_n - O_n)^2]^{1/2}$$

where n is the number of attributes in the dimensional space.

Multidimensional scaling analysis was performed in this study using a computer algorithm, called SCALE, which was available in the Resource Analysis Package (Tilmann, 1978) on the Michigan State University CDC 6500 computer system. For the purposes of this study, soil potential was defined as a function of the cost of corrective measures used to overcome soil hazards and the relative severity of limitations remaining after these measures are employed. These factors under consideration defined the set of orthogonal axes and also established a two-dimensional factor space for soil potential. The numerical values of each factor established a point or coordinate set for each soil in this two-dimensional factor space. The factors which exhibited the least limitations to the land use defined an optimum condition set and were also represented by a point in this factor space. The minimum limitation or optimum condition for each factor (O_n value in the equation above) was defined as the lowest cost for corrective measures of all the soils rated and the rating of slight for continuing limitations. The Euclidean distance between this optimum point and the point representing each soil was its soil potential index value normalized to a scale of 0 to 100. The index was then inverted so that soils with the highest soil potential would have the large numbers, while those with the lowest soil potential would have small numbers. As stated previously, each component of a soil complex was rated separately. The final rating of the entire unit was determined by multiplying the rating of each component by its estimated areal extent in the map unit and tallying these index values.

Assignment of Qualitative Ratings

Once the soil potential indices were determined, the next step was to assign the soils to qualitative classes of soil potential according to their soil potential for each land use. Four classes were provided for comparative ratings of soil potential: excellent, good, fair, and poor. These classes were defined in terms of the performance expected of a soil if technologically feasible measures are applied to overcome its limitations, the costs of such measures, and the severity of the limitations that remain after corrective measures have been applied. The following is a definition of each class:

> Excellent Soil Potential--Soils rated excellent have properties exceptionally favorable for the intended use. Soil limitations or restrictions are minor and can be corrected with usual management techniques or practices to assure high performance for the intended use. The initial installation and management costs to establish the use or maintain it are inexpensive compared to those on all other soils in the county. Continuing limitations are slight after these corrective measures have been applied. Soils rated excellent are the best in the county for the intended use.

> Good Soil Potential--Soils rated good have properties favorable for the intended use. Some soil limitations or restrictions exist, but measures necessary to overcome these limitations are available. The measures needed usually increase costs of establishing or maintaining the use, but are not generally prohibitive in relation to design costs for soils rated fair or poor. Limitations continuing after these corrective measures are installed are slight. Performance for the intended use can be expected to be good.

> Fair Soil Potential--Soils rated fair have many properties favorable for the intended use. One or more soil limitations exist that can be overcome with corrective measures, but limitations are primarily of a continuing nature requiring practices or designs that need to be maintained,

or are more difficult, unusual, and costly. Limitations continuing after these corrective measures have been applied are commonly moderate. Performance for the intended use can be expected to be fair.

Poor Soil Potential--Soils rated poor have properties unfavorable for the intended use. One or more soil limitations exist that are extremely difficult to overcome. The initial installation or maintenance cost for these measures, if available, are prohibitive as compared to those needed on all other soils in the country. Limitations continuing after these corrective measures are installed are severe and seriously detract from environmental quality or economic returns. Performance for the intended use can be expected to be poor. Soils rated poor are the worst in the county for the intended use.

There are many kinds of class determination techniques used by researchers, but these can be generally separated into three major groups (Robinson, Sale, and Morrison, 1978). The best known technique essentially classifies data by a series of equal steps based on the data range. These are calculated by merely dividing the range between the maximum and minimum values by the desired number of classes to obtain the common interval difference. This integer number is then successively added to each class limit starting with the lowest class to obtain the next highest class limit.

A second technique uses the parameters of a normal distribution, the mean and standard deviation, to form the interval class limits, such as the mean plus and minus one standard deviation, from one standard deviation to two standard deviations above the mean, and so on. The third common type of interval selection involves the use of quantiles or equal divisions of the data. These are calculated by arraying data observations by their magnitude from the lowest to the highest. If one wished to divide the data into five intervals, then one proceeds to count one-fifth of the number of data observations from the bottom to obtain the value of the first quantile value, and so on.

Prior to the advent of high-speed computers and efficiently written grouping-algorithms, it was an extremely time-consuming process to determine the consequences of employing different class intervals produced by these different methods. Computer programs are now available that will test the various sets of class intervals to see which best fits a researcher's data.[9] These will commonly output statistical measures that state the degree of homogeneity within groups, as well as differences between them, for each different class interval chosen.

A computer grouping program, called JENKS, was employed in this study to select class intervals for grouping soils into the four soil potential rating classes. The program was originally written by George Jenks at the University of Kansas (Jenks, 1976) and extensively modified at Michigan State University to run interactively on the University CDC 6500 computer system. The user is required to enter data values with identifying names or numbers along with specifying the desired number of class intervals. The program then computes statistically optimal class intervals for grouping the data by moving observations from one class to another

[9]Personal communication with Robert I. Wittick, Associate Professor, Department of Geography, Michigan State University, East Lansing, Michigan, November 10, 1978.

to minimize within class variance (homogeneity) and maximize between class variance (heterogeneity). This process continues until the sum of the square deviations between each observation and its class mean can no longer be increased and the goodness of variance is maximized. Table 3-8 lists the optimal class intervals for soil potential classes determined by the JENKS program, and their goodness of variance fit for selected land uses in Eaton County, Michigan.

Development of the Computer Masterfile

A computer disk file, cataloged as SOIL POTENTIAL, was created out of the detailed data base collected by preparing the soil potential ratings for Eaton County, Michigan. These data were entered to disc storage via normal telephone lines connecting a portable terminal with the Michigan State University CSC 6500 computer system. Every line or record in this file, one for each of the 45 soils mapped in Eaton County, contained the following data for each of the given land uses:

1. estimated dollar cost for practices or management alternatives that may be used to overcome soil limitations;
2. qualitative rating given to the degree of continuing limitations which remain after corrective measures have been applied;
3. the numerical soil potential index values; and
4. the soil potential classification.

Table 3-8. Assignment of soil potential classes by ranges in the soil potential index for selected land uses in Eaton County, Michigan.

Land Use	Soil Potential Class				Goodness of Variance Fit (percent)
	Excellent	Good	Fair	Poor	
Septic tank filter fields	100-82	81-32	31-5	4-0	98.17
Residential roads and streets	100-92	91-78	77-53	52-0	98.40
Dwellings with basement	100-83	82-60	59-28	27-0	97.50
Dwellings without basements	100-93	92-70	69-47	45-0	98.11
Residential waterlines	100-79	78-57	56-43	42-0	95.06

Each alphanumeric soil map symbol was assigned a unique integer sequence number (Table 3-9) to facilitate computer processing. The costs of corrective measures and soils potential index values were coded as integer numbers, the latter ranging from 0 to a maximum of 100. In addition to these variables, the qualitative classifications for continuing limitations and the soil potential classifications were entered as numeric codes (Table 3-10, 3-11).

The Remote Sensing Project at Michigan State University graciously provided a geocoded disk file containing soils and natural resource data for the study area (Windsor Township, of Eaton County). They had previously used it to demonstrate the utility of a computerized data processing system for regional water quality studies and general land use planning (RSP, MSU, 1976). Table 3-12 lists the data types and their resources included in this file. The general methods and procedures employed by these researchers to code these data are only briefly mentioned here. Readers are referred to the technical reports published by the Remote Sensing Project at Michigan State University for a detailed discussion of these specific techniques.[10]

The data file for Windsor Township was assembled using a grid-based geocoding procedure. This procedure is referred to grid-based because a grid network of equally spaced rows and columns is

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[10]See for example, "Report on the Natural Resource Information System Developed For the Tri-County Regional Planning Commission," 1976 and "A Recommended Procedure to Computerize Soil Maps," by S. E. Tilmann, 1977.

Table 3-9. Numeric coding scheme for soils mapped in Eaton County, Michigan

Code Number	Map Symbol	Soil Map Unit
1	Ad	Adrian muck
2	BbA	Bixby loam, 0-3% slope
3	Bh	Borrow land
4	BnB	Boyer loamy sand, 0-6% slopes
5	BnC	Boyer loamy sand, 6-12% slopes
6	BoB	Boyer sandy loams, 0-6% slopes
7	BoC	Boyer sandy loams, 6-12% slopes
8	BpD	Boyer-Spinks loamy sands, 12-18% slopes
9	BrA	Brady-Bronson sandy loams, 0-3% slopes
10	CaA	Capac loam, 0-3% slopes
11	CbB	Capac-Marlette loams, 1-6% slopes
12	Ch	Cohoctah fine sandy loam, frequently flood
13	Co	Colwood loam
14	Cp	Colwood loam, depressional
15	Ed	Edwards muck
16	Gf	Gilford sandy loam
17	HaB	Hillsdale sandy loam, 2-6% slopes
18	HaC	Hillsdale sandy loam, 6-12% slopes
19	Ho	Houghton muck
20	KbA	Kibbie fine sandy loam, 0-3% slopes
21	Le	Lenawee slilty clay loam, depressional
22	MaB	Marlette loam, 2-6% slopes
23	MaC	Marlette loam, 6-12% slopes
24	MaD	Marlette loam, 12-18% slopes
25	MaE	Marlette loam, 18-25% slopes
26	MbC3	Marlette clay loam, 6-12% slopes, severely eroded
27	MdA	Matherton loam, 0-3% slopes
28	MeA	Metamora-Capac sandy loams, 0-4% slopes
29	OsB	Oshtemo sandy loam, 0-6% slopes
30	OsC	Oshtemo sandy loam, 6-12% slopes
31	OwB	Owosso-Marlette sandy loams, 1-6% slopes
32	OwC	Owosso-Marlette sandy loams, 6-12% slopes
33	OwD	Owosso-Marlette sandy, loams, 12-18% slopes
34	Pa	Palms muck
35	Pr	Parkhill loam
36	Sb	Sebewa loam
37	Sh	Shoals-Sloan loams
38	SpB	Spinks loamy sand, 0-6% slopes
39	SpC	Spinks loamy sand, 6-12% slopes
40	StB	Spinks-Metea loamy sands, 0-6% slopes
41	StC	Spinks-Metea loamy sands, 6-12% slopes

Table 3-9. Continued

Code Number	Map Symbol	Soil Map Unit
42	TuA	Tuscola fine sandy loam, 0-4% slopes
43	WaA	Wasepi sandy loam, 0-3% slopes
44	WbA	Wasepi sandy loam, bedrock variant, 0-3% slopes
45	WnA	Winneshiek silt loam, 0-3% slopes

Table 3-10. Numeric coding scheme for the continuing limitations classification.

Rating Description	Coding Number
Slight	1
Moderate	2
Severe	3

Table 3-11. Numeric coding scheme for the soil potential classification.

Soil Potential Classification	Coding Number
Excellent	1
Good	2
Fair	3
Poor	4

Table 3-12. Data types and data sources included in the Windsor Township file.

Data Type	Data Source	Date	Scale of Original Map
Soil type	Eaton County Interim Soil Survey	1972	1:48,000
Slope	Same as soil type	1975	1:15,840
Drainage	Same as soil type	1975	1:15,840
Elevation	Dimondale, Eaton Rapids, Lansing South, Aurelius 7.5 minute quadrangles	1965 and 1973	1:24,000
Distance to water bodies	Same as elevation	1965 and 1973	1:24,000
Depth to bedrock	Geological Survey, DNR, Water well records	1968 to 1976	Interpolated from point data
Land cover/use	Eaton County Land Cover/ Use Inventory	1972	1:48,000

SOURCE: Michigan State University, Project for the use of Remote Sensing in Land Use Policy Formulation, "Report on the Natural Resource Information System Developed For the Tri-County Regional Planning Commission," 1976, p. 14.

superimposed over the different map documents (Table 3-12) to be input into the computer. The geocoding aspect of this technique refers to the referencing of these grid cells so that the computers can associate the locations at which the data have been collected with their locations on the maps which are to be produced or the properties for which data are to be summarized or analyzed.

Figure 3-2 illustrates this process using the encoding of a soils map as an example. As shown, a dot-grid of appropriate scale and resolution is prepared on a clear sheet of acetate with each cell referenced by its row-column coordinates. Rows and columns are numbered sequentially, starting from the upper left-hand corner. For example, the cell at the beginning of the first row (upper left) has the coordinates of 1,1; the cell in the far southeast corner has the coordinates of 8,8. By superimposing this dot grid onto the soil map, the soil occurring directly beneath each cell-centered dot can be assigned to that particular cell. This technique requires few operator decisions and map documents can be encoded rapidly.

The final product of this encoding process is a data matrix (Figure 3-2). Each number in this matrix represents the soil for that parcel of land underneath the corresponding dot on the grid. These data are recorded on a computer coding form, each line or record containing all of the data gathered from the factor maps (cover or land use, soil type, slope, drainage, etc.) for the respective cell (see Table 3-12). Soils and other natural resource data are recorded for each cell using numeric codes (Appendix D).

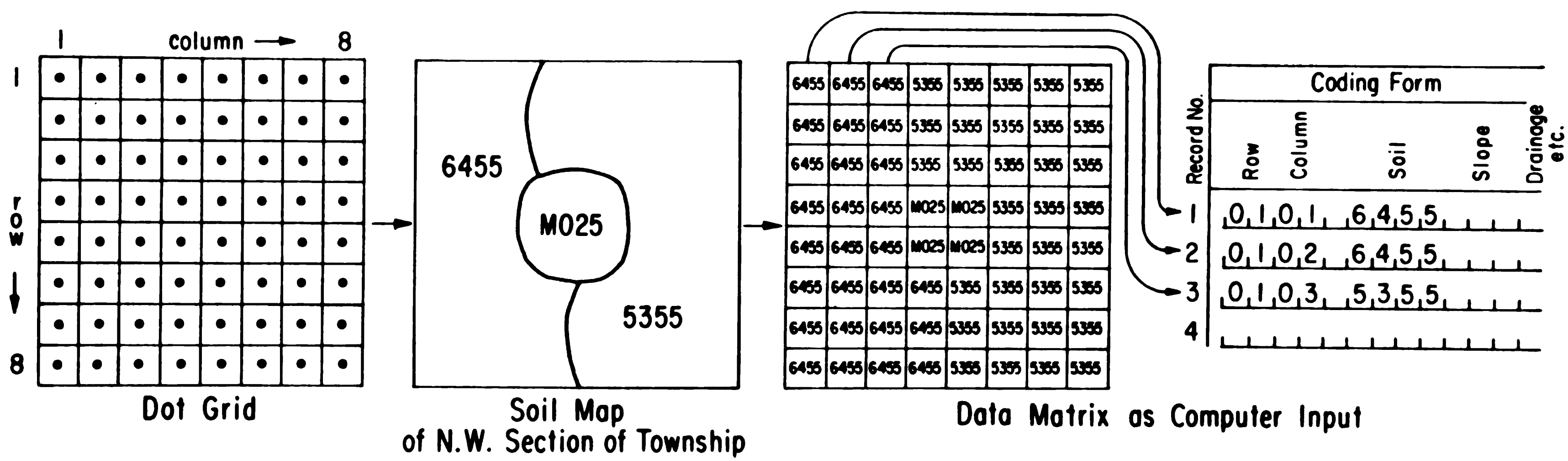


Figure 3-2.--Geocoding procedure using encoding of a soil map as an example.

A ten-acre dot grid was used by the Remote Sensing Project to encode the different factor maps (Table 3-12) for the Windsor Township file. Among the major considerations for this choice of grid sampling interval was its close correspondence with minimum mapping unit size of remote sensing imagery used for the township. At this resolution, the township file with 36 sections has 2,304 cells, each section having 64 cells (Figure 3-3). These cells are numbered consecutively so that the rows run from west to east (0-48) and columns run north to south (0-48). The interval between cells is 660 feet or 1/8th mile allowing the cell boundaries to correspond to section lines and roads.

A FORTRAN computer program was written to permit assignment of soil manuscript codes in the township file. A reference table was prepared where each interim soil map symbol was assigned the appropriate soil manuscript code and integer sequence number (Table 3-9). The program then became a simple table look-up procedure which changed one soil map code to another with the addition of new soil sequence numbers to each record in the file. These numeric codes were then used to access the previously stored data on soil potentials for five land uses in Eaton County, Michigan. These were added to each record in a revised computer master file for the township which was later copied to magnetic tape for permanent storage in the computer system. Appendix E shows the format of this revised file with space allocated for these new data.

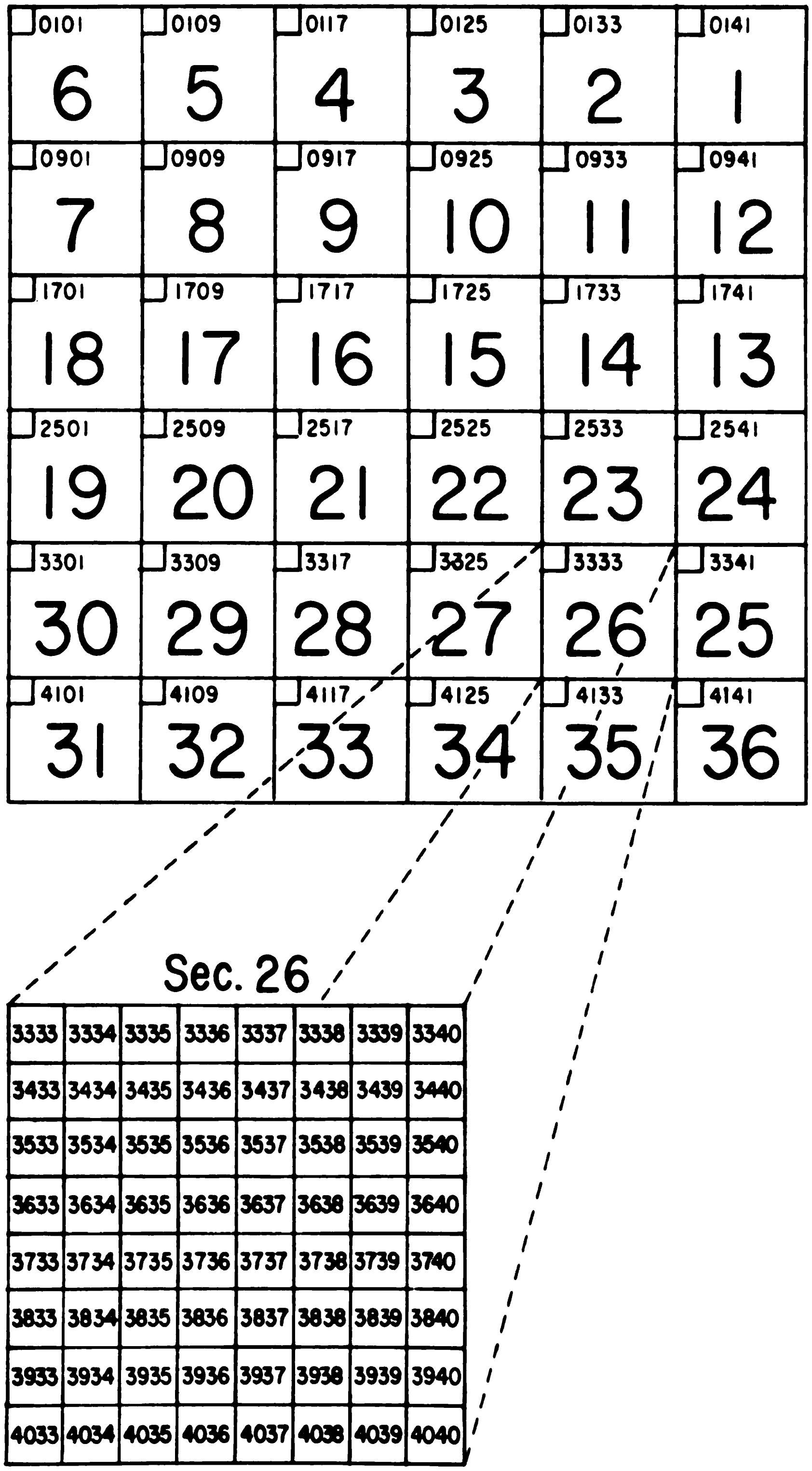


Figure 3-3.--Grid numbering system for Windsor Township file at a 10-acre cell size.

Data Analysis Process

A computer-assisted technique was developed to aid in the retrieval, manipulation, and display of stored soil potential ratings. A generalized flow chart illustrating the sequential steps in this process is presented in Figure 3-4. There are five major parts to this chart: the creation of the master file, the retrieval of selected data for analysis, the analysis strategy linking together specific RAP phases, the production of computer maps and tables of statistics, and the analysis and interpretation of the results. Notice that the process begins with the creation of a computer master file and ends with analysis and interpretation of the results. The specific underlying the creation of the master file used in this study were discussed in a previous section. Evaluation of the output from this study will be reserved to Chapters IV and V. Discussion of the intermediate steps between these phases will be specifically presented in the following sections.

Data Retrieval from the Masterfile

The Resource Analysis Program, called RAP, an interactive computer software system designed at Michigan State University (Tilmann, 1977b), was utilized to assist in the management, manipulation and graphic display of geocoded data stored in the computer masterfile. The program's analytical and graphic capabilities have been added to and modified by many contributors over a period of several years. This program has been well-documented

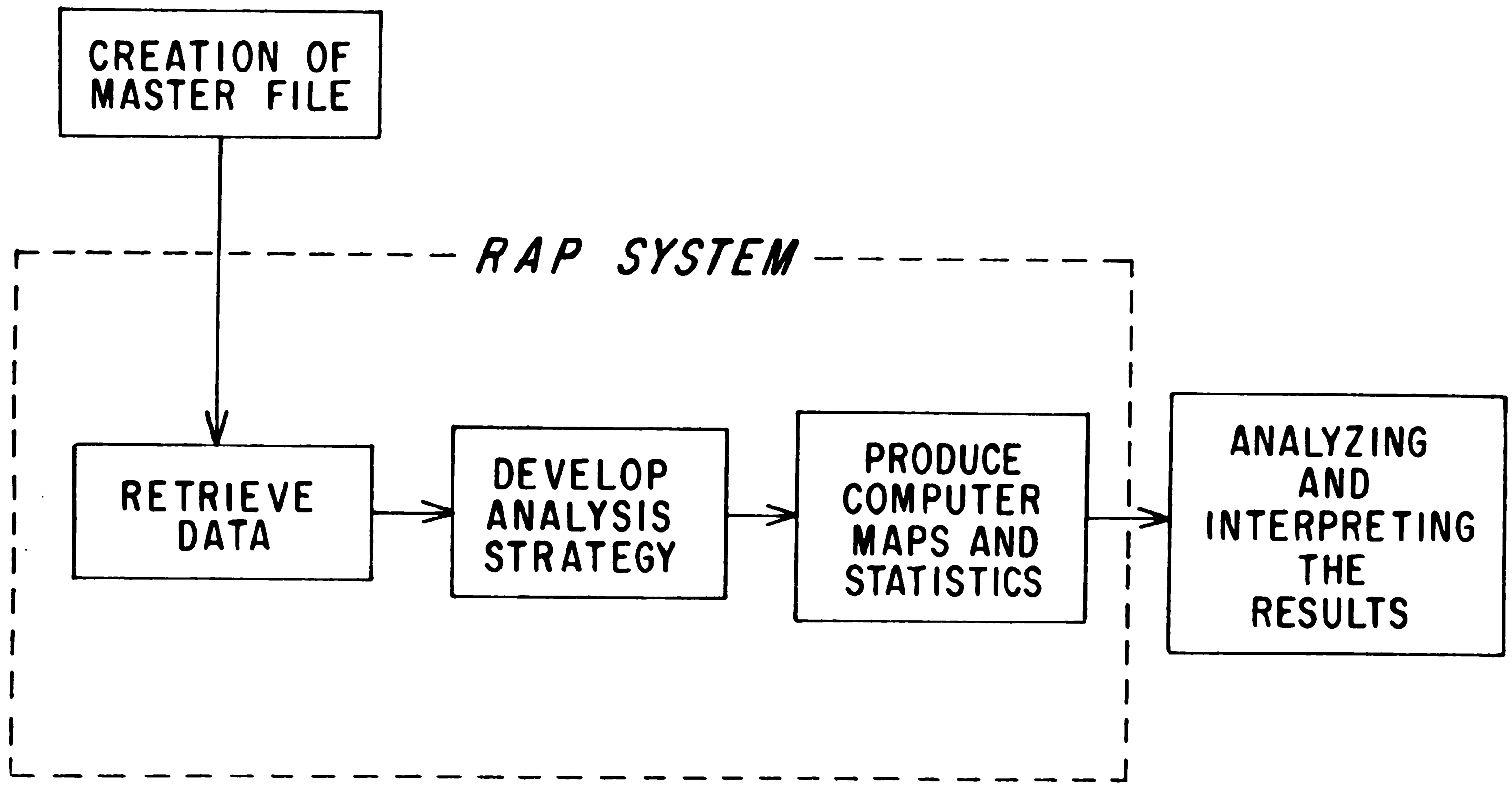


Figure 3-4.--Basic flow chart of data analysis process.

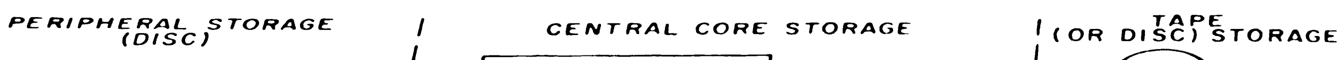
and is currently maintained on the CDC 6500 computer by the Remote Sensing Project at the University.

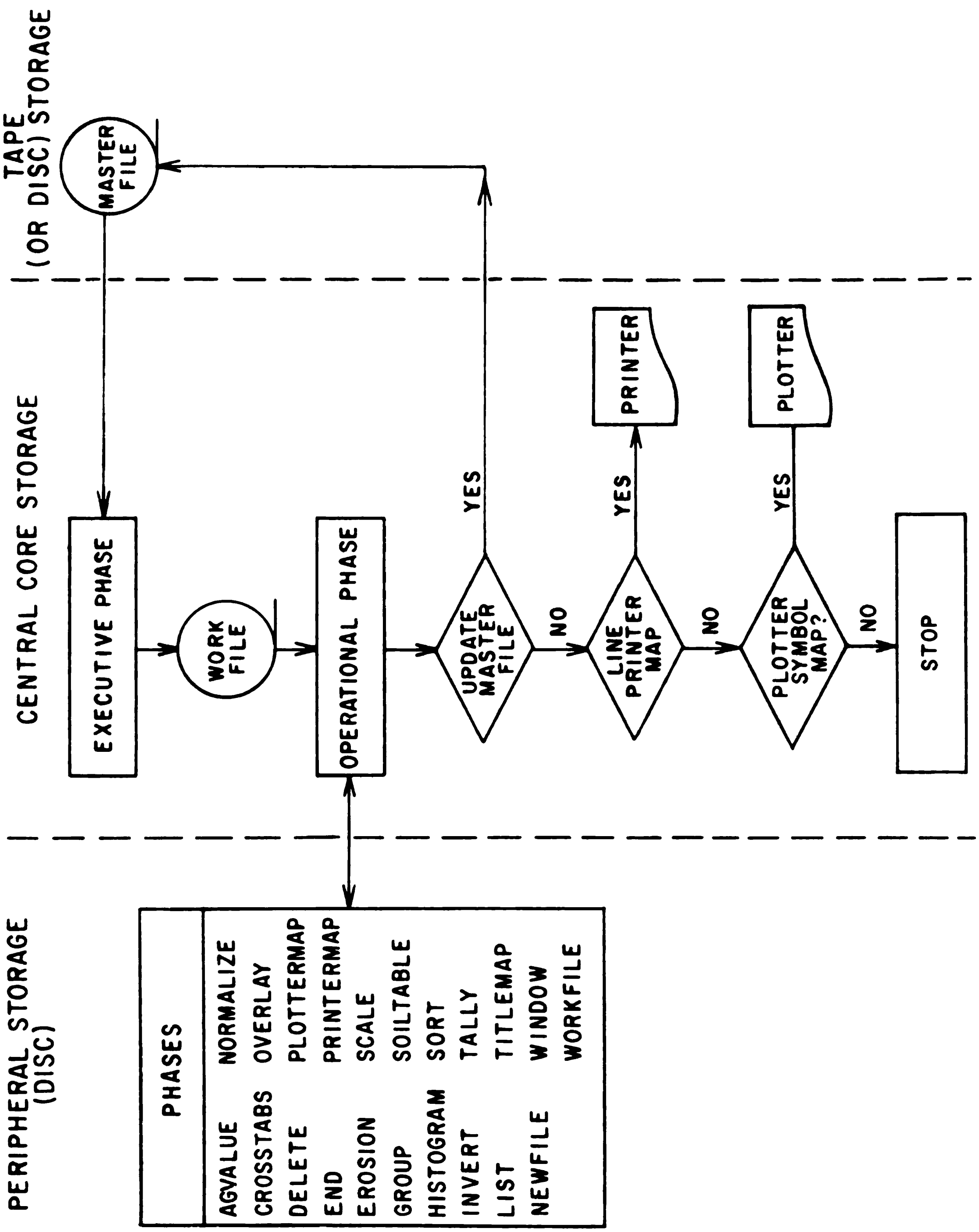
Figure 3-5 is a diagram of RAP's internal organization, a generalized graphic description of input, output, and sequencing of major operations. As shown, the grid-geocoded masterfile is stored external to the main program on cards, disk file, or magnetic tape. Users are required to attach this master file before RAP is executed. The program may be accessed either by batch or by terminal, although certain error checking features cannot be utilized fully from the batch mode. RAP was primarily written to be run interactively and, as such, internally prompts the user when data input from the terminal is required.

Upon initial execution of RAP the WORKFILE phase is first called to transfer user-specified data from the master file to a binary work file. This file serves as an intermediate data depository through which data are passed from one phase of the system to another. The user is required to specify the format type of the master file (i.e., sequential, raster, scan, or compressed boundary) and whether the file is card image or binary. The user must also indicate: the row and column of the master file grid, the number of factors to be retrieved from this file, the name for each factor, and the column location of each factor. Once answers to these questions are completed, RAP instructs the computer to retrieve the required factors from the master file and copy them on a binary workfile. RAP then relays a message (if by terminal)

Figure 3-5.--Schematic diagram of the RAP system.

SOURCE: Tilmann, 1978.


PERIPHERAL STORAGE (DISC)
CENTRAL CORE STORAGE
TAPE (OR DISC) STORAGE


PERIPHERAL STORAGE (DISC)
CENTRAL CORE STORAGE
TAPE (OR DISC) STORAGE
MASTER FILE
EXECUTIVE PHASE
WORK FILE
OPERATIONAL PHASE
UPDATE MASTER FILE
YES
NO
LINE PRINTER MAP
PRINTER
PLOTTER SYMBOL MAP?
PLOTTER
STOP
PHASES
AGVALUE
CROSSTABS
DELETE
END
EROSION
GROUP
HISTOGRAM
INVERT
LIST
NEWFILE
NORMALIZE
OVERLAY
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requesting the user to enter the name of the next phase directive and options selected.

Development of the Analysis Strategy

RAP offers a wide array of analytical and mapping programs which are directly accessible to a user during a computer run. Table 3-13 lists the phases available and their principal functions at the time of this writing. These phases are linked together with an overlay structure to allow intermediate data results from one phase to be entered onto the work file of another for further data manipulation. For example, results obtained through use of the EROSION phase could be input into the GROUP phase for assignment into user specified grouping ranges. Data and results from these analytical phases could then be mapped on a pen-and-ink plotter with the PLOTTERMAP phase or on a line printer with the PRINTERMAP or TITLEMAP phases to produce grey-tone maps.

The analysis strategy developed for this study basically consisted of linking together various RAP phases and choosing specific options available within each to produce a portfolio of display maps and accompanying tables of statistics. Included in this analysis strategy was the inevitable choice of which mapping option to use for display of the results. The present version of RAP offers two basic mapping alternatives. The PRINTERMAP phase uses the line printer to construct variable scale single or multi-character maps. The PLOTTERMAP phase uses the Calcomp plotter to draw a wider range of mapping characters, using different pen sizes

Table 3-13. Phases of RAP and their function.

Phase		Function
1.	AGVALUE	Determines assessment values for agricultural land based on current market values and soil indices.
2.	CROSSTABS	Generates 1- to 3-way cross tabulation tables.
3.	DELETE	Deletes a factor from the Work File.
4.	END	Stops execution of RAP.
5.	EROSION	Calculates on-site erosion susceptibility according to the Universal Soil Loss Equation.
6.	GROUP	Factor is grouped into numeric ranges and each range is assigned an integer number (mapping directive).
7.	INVERT	Factor range is inverted.
8.	LIST	Lists current attributes of Work File.
9.	NEWFILE	Writes a coded Work File onto TAPE 6.
10.	NORMALIZE	Normalizes the numeric range of a factor between default or user specified limits.
11.	OVERLAY	Generates comparative site indices by map overlay technique.
12.	PLOTTERMAP	Constructs variable scale symbol maps with plotter.
13.	PRINTERMAP	Constructs variable scale, single or multi-character symbol maps using line printer.
14.	SCALE	Generates comparative site indices using multidimensional scaling analysis.
15.	SOILTABLE	Retrieves soil-related properties from internal library tables.
16.	SORT	Assigns values (mapping directives) to pair-wise combinations of factors.
17.	TITLEMAP	Constructs a fixed-scale line printer map where each grid cell may contain up to three lines of title or numeric data.
18.	WINDOW	Develops a new work file based on row-column or data window of previous Work File.
19.	WORKFILE	Retrieves factors from Master File and constructs Work File.

SOURCE: Stephen E. Tilmann, Resource Analysis Program: User's Guide to RAP, 1978.

and colors on a larger variety of different drafting papers. Since the maps were to be reproduced in this report and used in formal presentations, a decision was made to utilize the PLOTTERMAP phase to graphically display the study results.

Production of Computer Maps and Statistics

Once the general analysis strategy was decided, the appropriate sequencing of RAP phases was determined from the RAP documentation (Tilmann, 1978) in order to produce the desired graphic and tabular output for the study. This was particularly important since the final product depends upon the order of RAP phases, as well as the specific options selected during the execution of each phase. By choosing the appropriate combination of analytical and mapping phases and their different options, eleven different computer maps, with accompanying tables of statistics were produced.

A land use/cover map was drawn using the CROSSTABS, GROUP, and PLOTTERMAP phases. The CROSSTABS program was employed first to determine the acreage distribution of each land use/cover category. Results indicated that a more meaningful computer map could be drawn by eliminating or combining those land use/cover categories with little or no reported acreage on this frequency table. The GROUP phase was then used to combine several of these categories. The grouped data were then mapped on the plotter with the PLOTTERMAP phase. Since the data were nominally scaled, they were portrayed as a letter code (i.e., A = residential, B = commercial, C = industrial, etc.) with boundaries drawn around those cells with the symbol type.

The GROUP and PLOTTERMAP phases were also used to prepare five soil potential maps for the portfolio, each one illustrating a different land use in Windsor Township. Soil potential ratings were coded by a simple integer sequence number (i.e., 1 = excellent, 2 = good, 3 = fair, and 4 = poor). The GROUP phase was used to assign each a mapping directive number which had an associated symbol type (octagons) in the PLOTTERMAP phase. The analyst proceeded next to the PLOTTERMAP program where soil potential ratings were graphically displayed on the pen-and-ink plotter. After each map was plotted, the CROSSTABS program was called to print a table listing the percent distribution of all soils in each soil potential class.

Soil limitation maps were next prepared which illustrated the same five land uses as displayed in the soil potential maps. In order to accomplish this task, the SORT phase was called after first retrieving the soil codes from the work file. This phase was employed to assign an integer sequence number to each soil indicating its soil limitation rating for each land use (i.e., 1 = slight, 4 = moderate, and 6 = severe). Existing tables (Feenstra, et al., 1978) and personal consultations with Delbert Mokma and Eugene Whiteside[11] were utilized to determine these soil

[11] Assistant Professor and Emeritus Professor, Department of Crop and Soil Science, Michigan State University, East Lansing, Michigan, respectively.

limitation ratings (i.e., slight, moderate, or severe). Each sequence number was then assigned a unique symbol type in the PLOTTERMAP phase to graphically display the soil limitations ratings for each land use. After each map was plotted, the CROSSTABS program was called to print a table giving the frequency distribution of all soils in each soil limitation class.

In addition to providing summary statistics for each map, the CROSSTABS phase was employed to print a 3 X 3 contingency table for each land use. The rows of this chart represented soils classified according to soil limitations (i.e., slight, moderate, or severe), and the columns representing soils classified according to soil potential (i.e., excellent, good, fair, or poor). The number shown in each matrix cell was the number of observations corresponding to the particular row and column. Row totals, column totals, and a grand total were printed for each matrix.

Summary

This chapter discussed the methods and techniques used to prepare soil potential ratings and their display in computer-drawn interpretive maps. Data sources required to prepare these ratings were identified. Detailed procedures used to collect and record these data were presented. The sequential data analysis process was outlined which assisted in the retrieval, manipulation, and display of these stored soil potential ratings for each of the five selected land uses.

CHAPTER IV

RESULTS AND DISCUSSION

The previous chapter reported on the research methods used to prepare soil potential ratings for five nonagricultural land uses and spatial displays of these ratings for soils in the study area. The purpose of this chapter is to present the data and analyze the results obtained for each of these selected land uses.

On-Site Waste Disposal

The soil potential index (SPI) and potential rating of each mapping unit for on-site waste disposal in Eaton County, Michigan, is shown in Table 4-1. The SPI ranges from a high of 100 for Bixby loam, 0 to 3 percent slopes, to a low of 1 for the Shoals-Sloan complex. As shown in this table, all map units were also arrayed from excellent to poor potential according to their soil potential index. The class intervals generated by the JENKS computer program (see Table 3-8) with the maximum goodness of variance fit (98.17%) were used to assign each mapping unit to one of the four qualitative rating classes indicating its relative potential for on-site waste disposal in this county. Note that areas mapped as water (e.g., lakes, rivers, swamps, wet spots, etc.) and borrow land in the county soil survey report were left unrated in Table 4-1. Properties

Table 4-1. Soil potential index and rating of soil mapping units for on-site waste disposal in Eaton County, Michigan.

Soil Potential Index	Soil Potential Rating	Soil Map Unit
100	Excellent	Bixby loam, 0 to 3 percent slopes
100	Excellent	Boyer loamy sand, 0 to 6 percent slopes
100	Excellent	Boyer sandy loams, 0 to 6 percent slopes
100	Excellent	Oshtemo sandy loam, 0 to 6 percent slopes
100	Excellent	Spinks loamy sand, 0 to 6 percent slopes
91	Excellent	Boyer loamy sand, 6 to 12 percent slopes
91	Excellent	Boyer sandy loams, 6 to 12 percent slopes
91	Excellent	Oshtemo sandy loam, 6 to 12 percent slopes
87	Excellent	Hillsdale sandy loam, 2 to 6 percent slopes
84	Excellent	Spinks-Metea loamy sands, 0 to 6 percent slopes
82	Excellent	Spinks loamy sand, 6 to 12 percent slopes
82	Excellent	Spink-Metea loamy sands, 6 to 12 percent slopes
80	Good	Boyer-Spinks loamy sands, 12 to 18 percent slopes
78	Good	Hillsdale sandy loam, 6 to 12 percent slopes
52	Good	Marlette loam, 2 to 6 percent slopes

Table 4-1. Continued.

Soil Potential Index	Soil Potential Rating	Soil Map Unit
52	Good	Owosso-Marlette sandy loam, 1 to 6 percent slopes
46	Good	Brady-Bronson sandy loams, 0 to 3 percent slopes
43	Good	Marlette loam, 6 to 12 percent slopes
43	Good	Marlette clay loam, 6 to 12 percent slopes, severely erodes
43	Good	Owosso-Marlette sandy loam, 6 to 12 percent slopes
31	Fair	Marlette loam, 12 to 18 percent slopes
31	Fair	Owosso-Marlette sandy loam, 12 to 18 percent slopes
25	Fair	Capac-Marlette loams, 1 to 6 percent slopes
25	Fair	Marlette loam, 18 to 25 percent slopes
8	Fair	Kibbie fine sandy loam, 0 to 3 percent slopes
8	Fair	Matherton loam, 0 to 3 percent slopes
8	Fair	Tuscola fine sandy loam, 0 to 4 percent slopes
8	Fair	Wasepi sandy loam, 0 to 3 percent slopes
8	Fair	Wasepi sandy loam, bedrock variant, 0 to 3 percent slopes
8	Fair	Winneshiek silt loam, 0 to 3 percent slopes
5	Fair	Metamora-Capac sandy loams, 0 to 4 percent slopes

Table 4-1. Continued.

Soil Potential Index	Soil Potential Rating	Soil Map Unit
1	Poor	Adrian muck
1	Poor	Capac loam, 0 to 3 percent slopes
1	Poor	Cohoctah fine sandy loam, frequently flooded
1	Poor	Colwood loam
1	Poor	Colwood loam, depressional
1	Poor	Edwards muck
1	Poor	Gilford sandy loam
1	Poor	Houghton muck
1	Poor	Lenawee silty clay loam, depressional
1	Poor	Palms muck
1	Poor	Parkhill loam
1	Poor	Sebewa
1	Poor	Shoals-Sloan loams
-	Unrated	Borrow land
-	Unrated	Water

of borrow land are clearly too variable to be estimated adequately and on-site sampling and testing are needed. These are areas where soil materials have been excavated (Appendix A) resulting in the destruction of the original soil profile.

The soil ratings shown in Table 4-1, and others reported in this study, should be cautiously used only for general planning purposes. These interpretations are not intended to eliminate the need for on-site sampling, testing, or detailed investigative studies of specific sites for the design and construction of engineering structures, such as roads, pipelines, and buildings. Soils are variable and, due to these variations, each mapping unit in a soil survey includes a range of soil properties because areas of other soils may be included within each delineated mapping unit. Soil mapping standards stated in the 1951 Soil Survey Manual (Soil Survey Staff, USDA, 1951) require that 85 percent of a soil area must conform to the range of properties defined by a soil name. Hence, 15 percent of an area within a soil boundary may be slightly different from the main body. However, no standard quality evaluations are currently in general use. In reality, the accuracy of the soil map units is commonly much less than 85 percent, and may average only 55 percent in glacial landscapes like those existing in Eaton County (Amos, 1973; Amos and Whiteside, 1975). This causes difficulties in the use of soil interpretations. For instance, if an individual, who is interested in constructing a septic tank filter field, determines from a soil survey that the dominant soil in a given delineation has good potential for this use, he cannot be 100 percent sure that the soil at a specific site will be the soil shown on the map. This is the reason for the admonition to do on-site evaluations for such uses. Consequently, soil interpretations, whether they are expressed in terms of limitations or potentials, do not apply to the inclusions in a mapping unit. More detailed studies are needed if specific sites, especially for nonagricultural use, are to be developed within a given soil map unit. Perhaps future descriptive legends will give more specific quantitative information about the composition of the soil map units.

Corrective Measures and Continuing Limitations

In cooperation with county, regional, and state health department officials, as well as local engineers and septic tank installers, designs of on-site waste disposal systems were identified for soils in Eaton County, Michigan. Appendix Table F1 lists soil factors affecting the use, recommended designs to overcome these limitations, and a statement of the kinds of limitations remaining after these designs are installed. As shown in this table, there are two feasible alternatives presently used in the study area to conventional septic tank filter field systems. These are mound systems and sewage holding tanks. Descriptions of these alternative designs, as well as variations of the conventional system, are presented below. Alternate non-conventional systems, such as composting toilets, oil flush toilets, incinerating toilets, and biological and chemical toilets, have been developed for handling home sewage, but have had little evaluation either by testing or by actual use in the Lansing metropolitan area.[12] Consequently, these new approaches to on-site waste treatment systems have not been considered here, although they may prove feasible in the future after further testing in the study area.

(1) Conventional septic tank system for on-site waste disposal.

The conventional septic system for on-site waste disposal consists of a septic tank, breather pipe, outlet sewer, and an underground soil absorption system for final disposal of the effluent (Figure 4-1). Sewage flows by gravity through a house sewer to the septic tank. This large rectangular or cylindrical tank, which can be made up of concrete, steel, or reinforced fiberglass, acts as a primary settling tank for the system. Waste water is retained in an appropriately sized septic tank[13] for a day or more allowing solids to separate from the liquid effluent. The heavier solids sink to the bottom of the tank where a "sludge blanket" develops, while lighter particles, including greases and oils, rise to the top to form a "scum layer." Anaerobic bacteria, organisms that live without oxygen, decompose some of the greases and heavy solids releasing methane and carbon dioxide gases which are vented from the tank through a stack vent commonly located on

[12] Personal communication with Durwood Zank, Sanitarian, Barry-Eaton District Health Department, Environmental Health Division, Charlotte, Michigan.

[13] The recommended minimum size tank for a single-family dwelling with 3 bedrooms or less is 1,000 gallons for Eaton County.

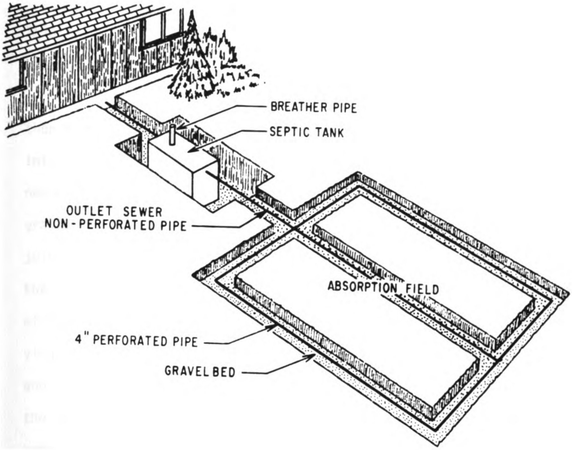


Figure 4-1.--Conventional septic system for on-site sewage disposal.

SOURCE: Witz, et al., 1974.

the roof of the dwelling. A breather or capped observation pipe (Figure 4-1) is used to provide convenient access for measuring the depth of undecomposed sludge and scum remaining in the tank. This material must be pumped out every 2 to 3 years under normal use to prevent clogging of the soil absorption fields.

In the conventional system, the remaining liquid effluent then flows from the septic tank through an outlet sewer (Figure 4-1) into the soil of an absorption field. This is a series of long narrow trenches, not more than 100 feet long, filled with crushed gravel or stone which surround perforated plastic pipe or open-joint agricultural drain tile. The liquid effluent seeps out of the holes in these pipes and into the surrounding soil where the effluent is then filtered, removing disease-causing bacteria and viruses, fine solids, and some nutrients. In a properly designed and installed septic system, biological and chemical processes in the soil allow for adequate filtering of bacteria and nutrients before the percolating effluent reaches the groundwater.

To rationally design a system for disposal of sewage effluent, an evaluation is commonly made by a local health department snaitarian of the soil profile (through soil borings or backhoe cuts) to locate limiting zones, and also percolation tests to determine the transmissibility of the natural soil formation. A limiting zone is any soil horizon, layer of bedrock, seasonally high water table, or other restricting layers that limit the soils' capability to purify the effluent before it reaches the groundwater. The depth to which these subsurface zones occur determines in large measure whether or not a conventional septic system can be installed. Where a restricting subsurface layer is closer than 3 feet to the ground surface as identified by soil borings alternate methods of effluent disposal will have to be considered by the potential home owner (Machmeier, 1977).

Soil percolation tests can also indicate whether the conventional-type disposal field can be satisfactorily used on particular soils. This is a standard test commonly used by sanitarians to evaluate the soils' ability to absorb sewage effluent. Soils have different capacities to handle septic tank effluent. Coarse-textured soils usually have rapid percolation rates and cannot adequately filter bacteria and viruses, while fine-textured soils have slow percolation rates not allowing enough water to pass through them. The conventional type disposal field is only satisfactory in soils having percolation rates faster than 60 minutes per inch. Results obtained from percolation tests for these soils, will provide valuable information on the required size of the absorption field to handle the sewage effluent discharged from the septic tank.

The size of the absorption field in a conventional septic system depends upon the porosity of the soil as measured by the percolation rate and the amount of sewage needed to be filtered by the absorption field. The daily peak flow of household sewage is commonly estimated by sanitarians, using the United States Public Health Service guidelines, at 75 gallons per day per person or 150 gallons per day per bedroom, assuming that two people occupy each bedroom in a residential dwelling (United State Public Health Service, 1958). The size of the absorption field required to adequately absorb this quantity of sewage effluent per bedroom is shown in Table 4-2 for soils with different percolation rates. The required absorption area for each bedroom is then multiplied by the number of bedrooms for the proposed house to calculate the total square feet of absorption area needed. This area is then divided by the proposed trench width to determine the total length of drainfield required.

The layout of the trench and distribution of effluent depends primarily upon the topography of the proposed dwelling site. Figure 4-1 illustrates the use of a conventional absorption system on level or nearly level soils, and Figure 4-2 shows a similar conventional system constructed on sloping soils. The later incorporates a method of effluent disposal (commonly referred to as serial distribution) by distributing effluent to the drain-field trenches with drop boxes. This allows each trench to absorb the maximum amount of liquid before additional quantities will flow to the drop box of the next trench in the series. Each portion of this subsurface system is thus used to full capacity to absorb the liquid effluent reducing the chances for lateral flow and surface seepage downslope.

(2) Elevated sand mound systems.

The conventional septic tank-soil absorption system is unsuitable in many locations because of site limitations, such as

Table 4-2. Minimum absorption area for conventional septic systems in square feet per bedroom as indicated by percolation rates in Eaton County, Michigan.

Percolation Rate[1] (minutes/inch)	Absorption Area Required[2] (square feet/bedroom)
0 - 10	165
11 - 15	190
16 - 20	220
21 - 25	260
26 - 30	300
31 - 40	350
41 - 45	375
46 - 60	425
61 or more	Use alternative systems

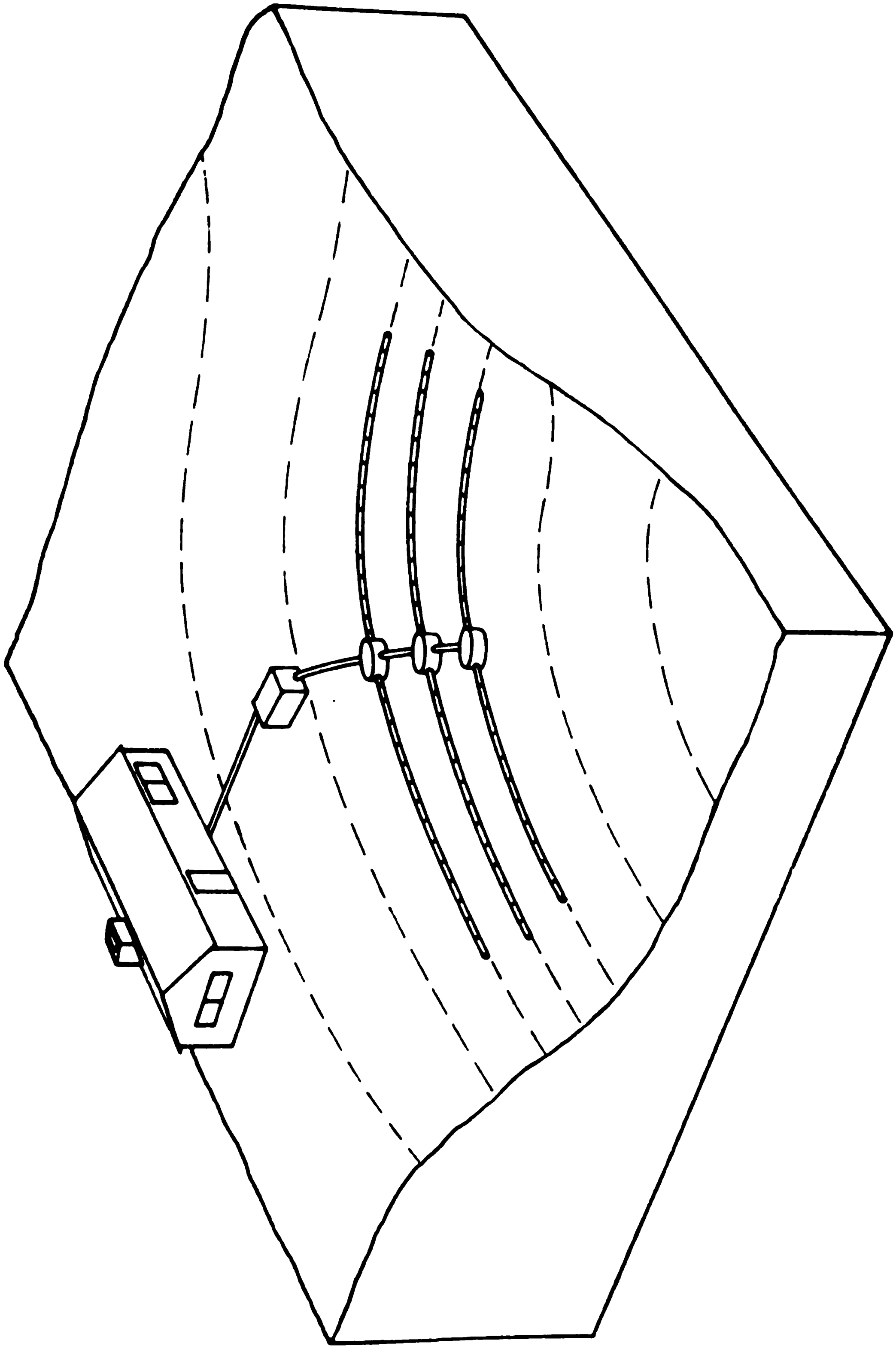
SOURCE: Barry-Eaton District Health Department, Sanitary Code Regulating Sewage Disposal, Table II.

[1]Time required for water to fall one inch.

[2]Trench width 18 to 36 inches.

Figure 4-2.--Conventional septic system on sloping site.

SOURCE: Machmeier, 1977.



slowly permeable soils, or soils over shallow bedrock or seasonally high ground water tables. The elevated sand mound (Figure 4-3) is an alternative system developed to overcome some of these limiting soil and site conditions and also allow for subsurface disposal of household effluent. This alternative system has been adapted and modified by numerous researchers for soil and site conditions prevalent in their particular states (Witz, et al., 1974; Bouma, 1975; Wooding, 1975; Machmeier, 1977).

A septic tank-mound system has three basic units: a septic tank, a pumping chamber, and an elevated sand mound (Figure 4-3). The size of the spetic tank is the same as that used in the conventional septic tank disposal systems. Effluent flows from this tank after primary treatment into the pumping chamber where an electric pump delivers a portion of it periodically under pressure for distribution in the mound. The sewage treatment mound is simply an above surface absorption field elevated by sand fill above the natural soil consisting of fill material, an absorption area, a distribution system made up of perforated pipes, a clay barrier, and topsoil (Figure 4-3). The effluent that is pumped into the mound through the distribution system slowly percolates downward through the fill materials where it is filtered before it reaches the natural soil. The clay barrier, which is built around the mound, prevents effluent from moving out of the mound, promotes runoff, and provides frost protection. The topsoil over the entire area of the mound aids in establishing and maintaining a suitable grass cover to prevent erosion.

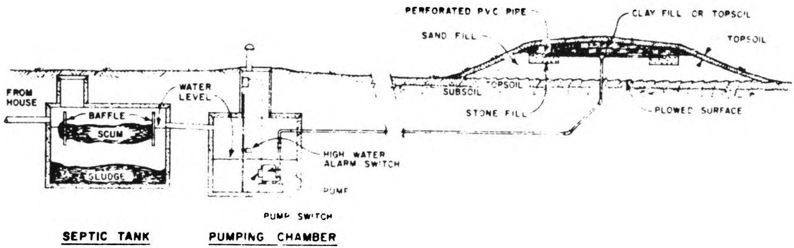


Figure 4-3.--A septic tank-mound system.

SOURCE: Bouma, 1975.

The mound system is designed to serve rather different functions depending upon the kind of problem soil and site conditions (Converse, Carlile, and Petersen, 1977). Permeable soils over creviced or porous bedrock and seasonally high water tables less than 5 feet below the soil surface are unsuitable for conventional septic systems because inadequate soil is available to purify the liquid effluent before it reaches the bedrock or water table. To compensate for these limitations, the absorption field is elevated above the natural soil with sand fill increasing the amount of soil available for purification before the percolating effluent reaches the ground water or rock strata.

The mound serves an entirely different function for slowly permeable soils (slower than 60 minutes per inch percolation). In addition to having slowly permeable subsoil horizons, these soils commonly have seasonally high water tables within 2 feet of the ground surface, particularly in the early spring and fall. At these times of the year, infiltrating water is unable to percolate fast enough through the slowly permeable subsoil resulting in flooding and ponding. To overcome these serious limitations, the soil absorption field can be raised above the natural soil by building the field in a mound of sand fill. This removes the absorption field from the wet and slowly permeable subsoil and places it in a moist permeable sand. Bouma (1975) has recognized several main advantages to this technique:

> First, the percolating liquid can then enter the more permeable natural topsoil over a larger area where it can move

> out laterally until absorbed by the less permeable subsoil. Second, the biological slimes that eventually develop at the seepage trench bottom will not clog the sandy fill to the degree they would in the less permeable natural soil. Finally, no construction is done in the topsoil where smearing and compaction is often unavoidable.

As with any soil absorption system, the design of the mound is based on the expected daily wastewater volume and the natural soil characteristics. The mound must be appropriately sized for a given dwelling to accept the daily flow of effluent without surface seepage. These systems require increased maintenance and power costs relative to conventional septic tank-absorption field systems because the electric pump must be kept in good running order for proper distribution of the effluent in the mound. The reader is referred to Converse, Carlile, and Petersen (1977) for an excellent discussion of mound design, construction procedures, and maintenance practices.

(3) Holding tanks.

Where on-site waste disposal is not possible because of soil and site conditions, sewage must be discharged into a holding tank from which it is pumped and transported to a municipal sewage treatment plant or landfill disposal site. Holding tanks are usually permitted in Michigan only on lots where a residence is already located, rarely for new home construction.[14] As with all septic tank-disposal systems, a permit for a holding tank must be

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[14]Personal communication with John Long, Sanitarian, Michigan Department of Health, Environmental Health Division, Lansing, Michigan.

obtained from the local health department before construction can begin. Although a permit may be granted in some instances for new homes, the homeowner may wish to reconsider building on his lot because of the holding tank's high cost.

A holding tank is essentially constructed out of the same water tight materials as is the septic tank (Figure 4-4). Its recommended size is commonly at least 2,000 gallons (Machmeier, 1977). The tank must be sited to allow for convenient access to the sewage pump truck in all-weather conditions. Water flowing into the holding tank should be metered in order to determine when the tank must be pumped. The charge for hauling the sewage is based on this water meter reading. Water use economy is a must to reduce daily sewage flow and frequency of pumping. The costs of operating holding tanks is not well documented in the literature, although studies in Maine and Wisconsin indicate that the cost may be as high as $1,000 per year for a family of four with a pump out once a month (Maine Department of Environmental Protection, 1974).

Cost of Corrective Measures

Table 4-3 presents the estimated costs of applying different corrective measures to overcome soil limitations for on-site waste disposal in Eaton County, Michigan. Note that these costs are general estimates in 1978 dollars for installing corrective measures on sewage disposal systems, and are not intended to eliminate the need for cost estimating by local contractors on a site-by-site

Figure 4-4.--A holding tank system.

SOURCE: Machmeier, 1977.

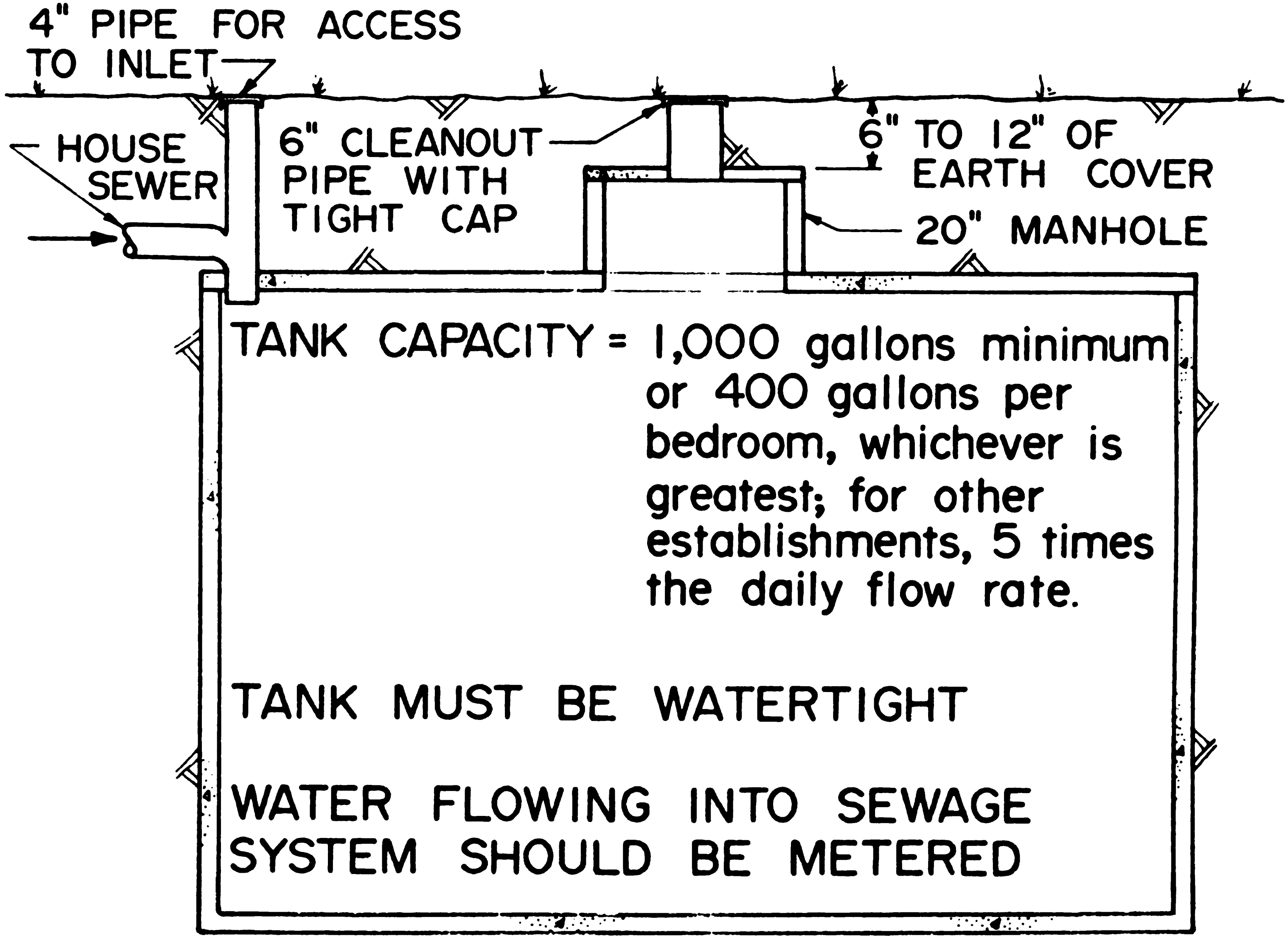

4" PIPE FOR ACCESS
TO INLET
HOUSE
SEWER
6" CLEANOUT
PIPE WITH
TIGHT CAP
6" TO 12" OF
EARTH COVER
20" MANHOLE
TANK CAPACITY = 1,000 gallons minimum or 400 gallons per bedroom, whichever is greatest; for other establishments, 5 times the daily flow rate.
TANK MUST BE WATERTIGHT
WATER FLOWING INTO SEWAGE
SYSTEM SHOULD BE METERED

Table 4-3. Soil limitations and estimated costs of applying different corrective measures for on-site waste disposal in Eaton County, Michigan.

Soil Map Unit	Soil Limitation	Initial Cost (1978)	Corrective Measure
Adrian muck	Severe	3000	Holding tank
Bixby loam, 0 to 3 percent slopes	Slight	800	Conventional system
Borrow land	Properties too variable to be interpreted		
Boyer loamy sand, 0 to 6 percent slopes	Slight	800	Conventional system
Boyer loamy sand, 6 to 12 percent slopes	Moderate	1000	Conventional system
Boyer sandy loams, 0 to 6 percent slopes	Slight	800	Conventional system
Boyer sandy loams, 6 to 12 percent slopes	Moderate	1000	Conventional system
Boyer-Spinks loamy sands, 12 to 18 percent slopes	Severe	1250	Conventional system
For Spinks part see Spinks series			
Brady-Bronson sandy loams, 0 to 3 percent slopes	Severe	2700	Mound system
For Bronson part see Bronson series			
Bronson series	Moderate	800	Conventional system
Mapped only in a complex with Brady soils			
Capac loam, 0 to 3 percent slopes			
Capac-Marlette loams, 1 to 6 percent slopes	Severe	3000	Holding tank
For Marlette part see Marlette series			
Cohoctah fine sandy loam, frequently flooded	Severe	3000	Holding tank
Colwood loam	Severe	3000	Holding tank
Colwood loam, depressional	Severe	3000	Holding tank
Edwards muck	Severe	3000	Holding tank
Gilford sandy loam	Severe	3000	Holding tank
Hillsdale sandy loam, 2 to 6 percent slopes	Slight	1050	Conventional system
Hillsdale sandy loam, 6 to 12 percent slopes	Moderate	1250	Conventional system
Houghton muck	Severe	3000	Holding tank

Table 4-3. Continued

Table 4-3. Continued

Soil Map Unit	Soil Limitation	Initial Cost (1978)	Corrective Measure
Kibbie fine sandy loam, 0 to 3 percent slopes	Severe	2700	Mound system
Lenawee silty clay loam, depressional	Severe	3000	Conventional system
Marlette loam, 2 to 6 percent slopes	Moderate	1800	Conventional system
Marlette loam, 6 to 12 percent slopes	Moderate	2000	Conventional system
Marlette clay loam, 6 to 12 percent, severely eroded	Moderate	2000	Conventional system
Marlette loam, 12 to 18 percent slopes	Severe	2250	Conventional system
Marlette loam, 18 to 25 percent slopes	Severe	2500	Conventional system
Matherton loam, 0 to 3 percent slopes	Severe	2700	Mound system
Metamora-Capac sandy loam, 0 to 4 percent slopes	Severe	2700	Mound system
For Capac part see Capac series			
Metea			
Mapped only in complex with Spinks soils			
Metea part of Spinks-Metea loamy sands, 0 to 6 percent slopes	Moderate	1800	Conventional system
Metea part of Spinks-Metea loamy sands, 6 to 12 percent slopes	Moderate	2000	Conventional system
Oshtemo sandy loam, 0 to 6 percent slopes	Slight	800	Conventional system
Oshtemo sandy loam, 6 to 12 percent slopes	Moderate	1000	Conventional system
Owosso-Marlette sandy loams, 1 to 6 percent slopes	Moderate	1800	Conventional system
For Marlette part see Marlette series			
Owosso-Marlette sandy loams, 6 to 12 percent slopes	Moderate	2000	Conventional system
For Marlette part see Marlette series			

Table 4-3. Continued

Soil Map Unit	Soil Limitation	Initial Cost (1978)	Corrective Measure
Owosso-Marlette sandy loams, 12 to 18 percent slopes	Severe	2250	Conventional system
For Marlette part see Marlette series			
Palms muck	Severe	3000	Holding tank
Parkhill loam	Severe	3000	Holding tank
Sebewa loam	Severe	3000	Holding tank
Shoals-Sloan loams	Severe	3000	Holding tank
For Sloan part see Sloan series			
Sloan series	Severe	3000	Holding tank
Mapped only in complex with Shoals series			
Spinks loamy sand, 0 to 6 percent slopes	Slight	800	Conventional system
Spinks-Metea loamy sands, 0 to 6 percent slope	Slight	800	Conventional system
For Metea part see Metea series			
Spinks loamy sand, 6 to 12 percent slopes	Moderate	1000	Conventional system
Spinks-Metea loamy sands, 6 to 12 percent slopes	Moderate	1000	Conventional system
For Metea part see Metea series			
Spinks part of Boyer-Spinks loamy sands, 12 to 18 percent slopes	Severe	1250	Conventional system
Tuscola fine sandy loam, 0 to 4 percent slopes	Severe	2700	Mound system
Wasepi sandy loam, 0 to 3 percent slopes	Severe	2700	Mound system
Wasepi sandy loam, bedrock variant, 0 to 3 percent slopes	Severe	2700	Mound system
Winneshiek silt loam, 0 to 3 percent slopes	Severe	2700	Mound system

basis. The dollar figure listed in Table 4-3 is the mean of the range in costs (Appendix Table C1) for installing the different corrective measures for each soil. These were computed from cost analyses of installed systems obtained from septic tank installers, engineers, and local health department personnel in the study area.

The average initial costs of installing corrective measures on different soils for home sewage disposal in Eaton County ranges from $800 to $3,000 (Table 4-3). These data clearly indicate the need for additional investment and alternative nonconventional systems for adequate sewage disposal in soils with moderate to severe limitations. Soils with slight limitations (e.g., Bixby loam, Hillsdale sandy loam, 2 to 6 percent slopes) require only an initial investment of about $800 to $1,050 for installation of conventional septic tank-disposal systems, while those soils with moderate limitations (e.g., Hillsdale sandy loam, 6 to 12 percent slopes, Marlette loam, 2 to 6 percent slopes) require an expenditure of $1,000 to $2,000 to install similar conventional systems. Initial costs for soils with severe limitations (e.g., Adrian muck, Houghton muck, Tuscola fine sandy loam, 0 to 4 percent slopes) are higher, ranging from $1,250 to $3,000. In addition to the increased costs for installation, alternative nonconventional systems, such as mound systems or holding tanks, are necessary on many of these soils (Appendix Table F-1). These systems require increased maintenance and monitoring relative to conventional systems for home waste disposal.

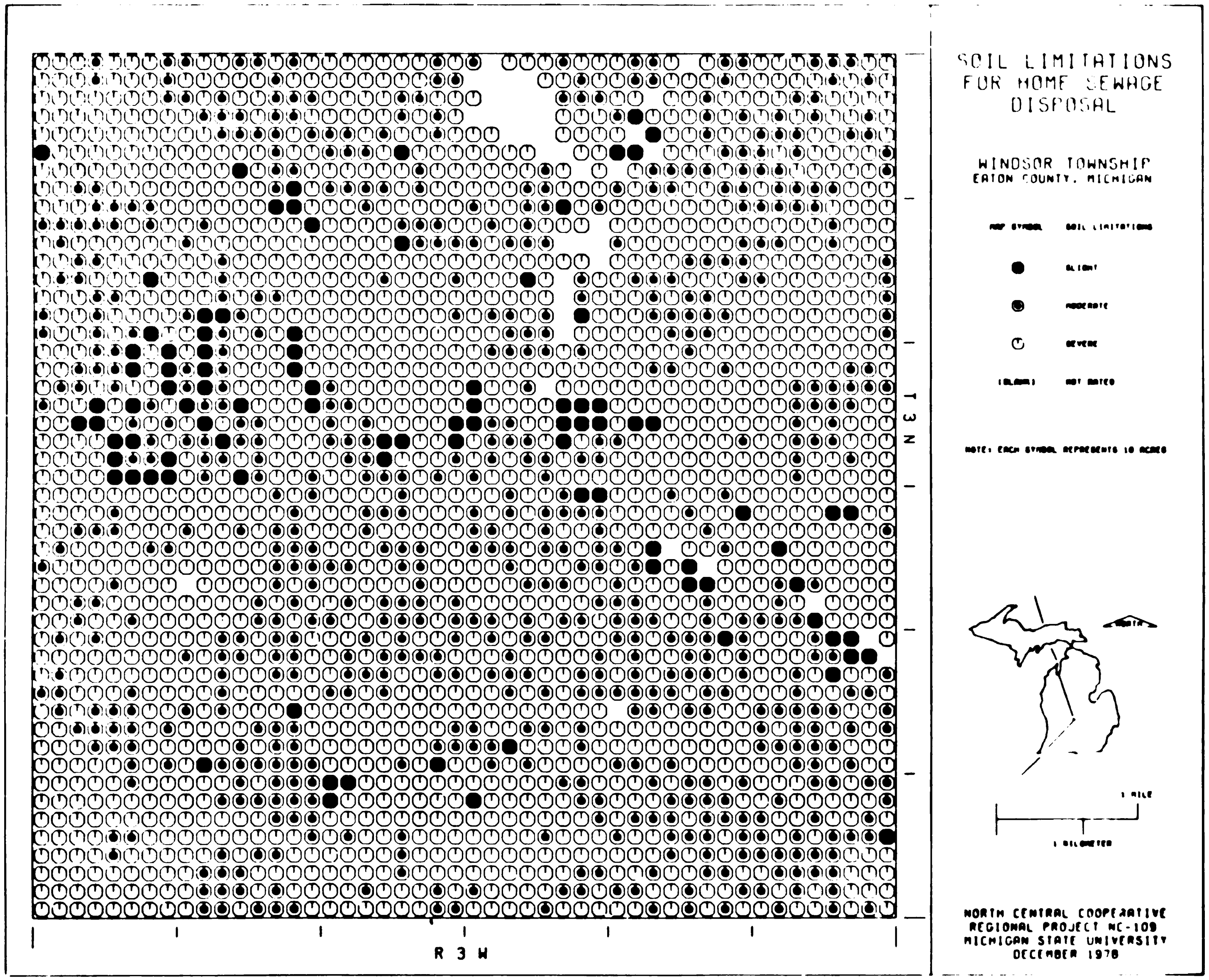
Computer Output

The soil potential ratings generated in the study and soil limitations gathered from engineering interpretation tables in the Eaton County Soil Survey (Feenstra, et al., 1978) were entered into a grid-geocoded computer file for Windsor Township, Eaton County, Michigan. These data were then subsequently mapped using the PLOTTERMAP phase of RAP and the university Calcomp plotter. The computer-generated maps developed here demonstrate the unique graphic capabilities of the RAP system to facilitate a visual understanding of soil interpretations for different nonagricultural land uses.

Figure 4-5 illustrates the locations of cells with limitations for home sewage disposal and offers an interesting picture. This computer-generated plotter map was drawn using concentric octagons to produce a visual density effect. The darker octagons on the map represent areas which have fewer limitations for home sewage disposal than other areas represented by lighter-shaded octagons. Each of the symbols on the map represents the appropriate rating for a 10-acre grid cell. Borrow land and water areas, including lakes and river, were left unrated in the study and show up as blank cells on the map.

In viewing Figure 4-5 it is readily apparent that much of the land area in the township has severe limitations for home sewage disposal. Most notable perhaps is the area which straddles "Old Maid Swamp" (see Figure 1-3) in the northwest portion of the

Figure 4-5.--Computer-drawn interpretive map illustrating soil limitations for on-site waste disposal in Windsor Township.


SOIL LIMITATIONS
FOR HOME SEWAGE
DISPOSAL
WINDSOR TOWNSHIP
EATON COUNTY, MICHIGAN
MAP SYMBOL
SOIL LIMITATIONS
SLIGHT
MODERATE
SEVERE
(BLANK)
NOT RATED
NOTE: EACH SYMBOL REPRESENTS 10 ACRES
NORTH
1 MILE
1 KILOMETER
NORTH CENTRAL COOPERATIVE
REGIONAL PROJECT NC-109
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township. A study of the soils map, sheet 23, in the Soil Survey of Eaton County, further indicates that the Adrian, Colwood, Edwards, Gilford, Houghton, Palms, and Parkhill soils dominate the landscape. These are nearly level, poorly and very poorly drained, mucky and loamy soils in depressions and drainageways (Table 1-1 and Appendix A). These soils are not well suited for home sewage disposal because they have high water tables for most of the year, and obviously have poor filtration capabilities due to these wet conditions.

A second area in Figure 4-5 is the northeast portion of the township, located east of the Grand River (Figure 1-3), also has predominantly severe limitations for home sewage disposal. A study of the soils map, sheet 30, in the soil survey report of the county, revealed that the Capac soils dominate this landscape. These are slowly permeable soils with water tables high enough to be troublesome for long periods. They present serious problems for installation of soil seepage systems because of severe limitations imposed by both slow soil permeability in clayey subsoil horizons (percolation rates slower than 60 minutes per inch) and seasonally high ground water tables (commonly less than 2 feet below the soil surface).

A third area in Figure 4-5 that stands out with predominantly severe limitations for home sewage disposal is situated near the King and Carleton drains (Figure 1-3) in the southwest portion of the township. A visual inspection of the soils map, sheet 35, in the soil survey of the county, shows that the Capac, Gilford, Houghton, and Sebewa soils dominate this area's landscape. Another area on the map with similar soils is located in the south-central portion of the township in proxmity to the upper Skinner Drain Extension (Figure 1-3). As previously mentioned, these soils are sure to present problems for conventional on-site waste disposal because of their seasonally high water tables and slow percolation rates in subsoil horizons.

Figure 4-5 also shows a few areas with only slight limitations for home sewage disposal. The spatial distribution of these soil areas is almost exclusively concentrated in the west-central portion of the township adjacent to U.S. Highway 27 and in proximity to West Windsor (Figure 1-2). A second area with similarly rated soils is located in the center of the township (Figure 4-5) within the corporate boundary of the Village of Dimondale (Figure 1-2). A visual examination of the soil map, sheets 29 and 30, indicates that Bixby, Boyer, Hillsdale, and Spinks soils tend to dominate these two areas. Generally, these soils are well drained, sandy loams or loamy sands with moderately rapid to rapid permeability. They require only minimal expenditure for installation of soil seepage systems because of these soil conditions, although those with rapid permeability must be sited appropriately to avoid pollution of shallow ground water supplies and nearby water courses, such as drains, lakes, and rivers.

The spatial distribution of soil areas with moderate limitations is also well illustrated in Figure 4-5. These areas are scattered throughout the map, especially concentrated in the southeast quadrant of the township. A study of the soil map, sheet 36, of the soil survey of the county, indicates that Marlette and Owosso soils dominate this area's landscape. Generally, these are well drained and moderately well drained gently sloping to hilly soils on till plains and moraines (Table 1-1 and Appendix A). Those soils with a moderate rating are only gently sloping to sloping; moderately steep to hilly soils have severe limitations due to slope. The moderately slow permeability of the subsoil horizons of these soils (percolation rate commonly between 45 and 60 minutes per inch) imposes moderate limitations for their use in home sewage disposal. Conventional soil absorption systems with serial distribution can be enlarged to compensate for this soil restriction, although obviously at increased costs relative to those systems designed for soils with only slight limitations.

Table 4-4 shows the percent and approximate acreage of soils in Windsor Township with different degrees of limitations for home sewage disposal. The calculations are based on the number of cells in each category (slight, moderate, severe, unrated) as plotted in Figure 4-5. According to the information presented in this table, 968, 8,848, and 12,810 acres have slight, moderate, and severe limitations for on-site sewage disposal in Windsor Township, respectively. This total acreage accounts for 98.2 percent of the land area in the township (22,625 acres). The remaining acreage (415) is water and borrow land left unrated.

Table 4-4. Proportionate extent and approximate acreage of soils classified by soil limitations and potentials for on-site waste disposal in Windsor Township, Eaton County, Michigan.

Degree of Soil Limitation	Soil Potential Rating: Excellent		Good		Fair		Poor		Unrated		Total	
	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres
Slight	4.2	968	———		———		———		———		4.2	968
Moderate	1.4	323	37.0	8525	———		———		———		38.4	8848
Severe	———		2.5	576	9.9	2281	43.2	9953	———		55.6	12810
Unrated	———		———		———		———		1.8	415	1.8	415
Total	5.6	1291	39.5	9101	9.9	2281	43.2	9953	1.8	415	100.0	23040

NOTE: Calculations are based on Figures 4-5 and 4-6 (2304 cells, 10 acres per cell).

These data then indicate that 42.6 percent of the land (9,816 acres) in the township has slight or moderate limitations for on-site sewage disposal, and is therefore suitable for use of conventional septic tank-soil absorption system, while more than half of the land area (55.6%) has severe soil restrictions for these systems.

With the advent of new technologies to overcome or treat moderate and severe soil limitations, significant changes can occur in the amount of suitable land for nonagricultural land uses. Table 4-4 shows the proportionate extent and approximate acreage of soils in Windsor Township classified according to their potential for home sewage disposal. As indicated by the totals at the bottom of the table, 1,291, 9,101, 2,281, and 9,953 acres have excellent, good, fair, and poor potential, respectively, for on-site sewage disposal in the township. Further study of these data reveals that out of the 12,810 acres of land in the township which are rated as having severe soil limitations for on-site sewage disposal, over 11 percent of this land area has good or fair soil potential for this land use. That is, assuming that modifications of conventional systems and mount systems are installed. This is a significant increase of 32 percent, 2,857 acres, in the amount of land that would be suitable for on-site waste disposal in the township. This additional area that would become suitable has either soil permeability rates and depth to seasonally high water tables or restrictive subsoil horizons presently adequate for mound systems, or soil slope gradients acceptable for specially engineered conventional septic tank-absorption systems with serial distribution of effluent. With further research in home waste disposal technology, it may be possible in the future to construct mound systems or other alternative systems on soils with high water tables within 2 feet of the surface without resorting to less desirable and expensive alternatives, such as holding tanks.[15] Thus, small but significant additional acreages of soils, now rated as having poor potential in Windsor Township (43.2 percent) would have increased soil potential for home sewage disposal.

The locations of cells with different soil potentials for home sewage disposal are illustrated in Figure 4-6. It is readily apparent that several areas on the map stand out as particularly suitable for such uses. Most notable, perhaps, are the areas in the northwest quandrant of the township, specifically in sections 7, 8, 17, and 18 (Figure 1-2). Much of these areas have either excellent, good, or fair soil potential for home sewage disposal. By comparing Figure 4-5 with Figure 4-6, it is evident that soils in these areas, rated as having severe soils limitations, now have fair or good potential for on-site waste disposal. Other areas on these two maps show similar changes as well.

The introduction of these modified conventional systems, as well as non-conventional systems for home sewage disposal, naturally poses a host of serious questions regarding land use.

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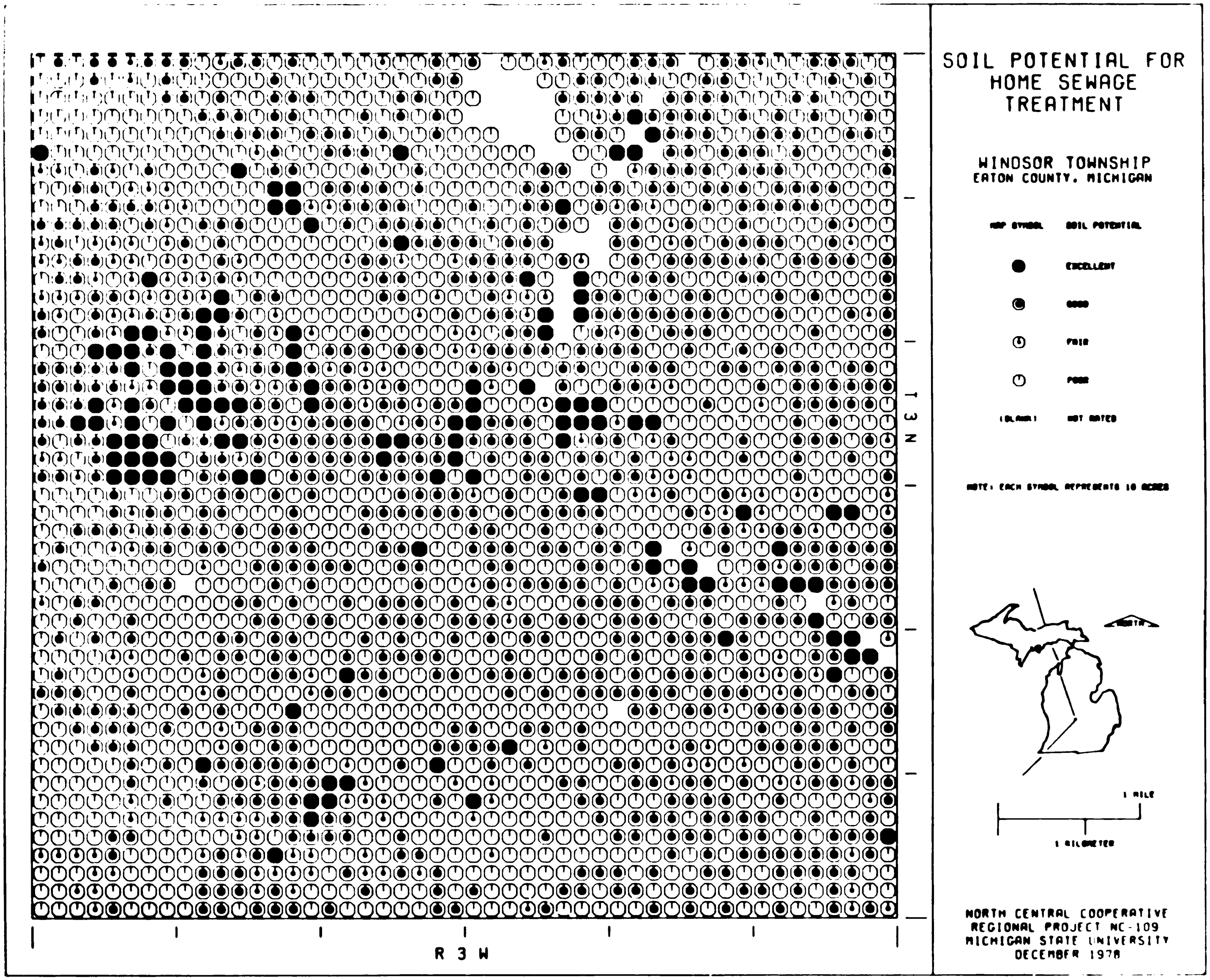
[15] Personal communication with E. J. Tyler, Assistant Professor, Soil Science Department, University of Wisconsin, Madison, Wisconsin.

Figure 4-6.--Computer-drawn interpretive map illustrating soil potential for on-site waste disposal in Windsor Township.


SOIL POTENTIAL FOR
HOME SEWAGE
TREATMENT
WINDSOR TOWNSHIP
EATON COUNTY, MICHIGAN
MAP SYMBOL
SOIL POTENTIAL
EXCELLENT
GOOD
FAIR
POOR
(BLANK)
NOT RATED
NOTE: EACH SYMBOL REPRESENTS 10 ACRES
NORTH
1 MILE
1 KILOMETER
NORTH CENTRAL COOPERATIVE
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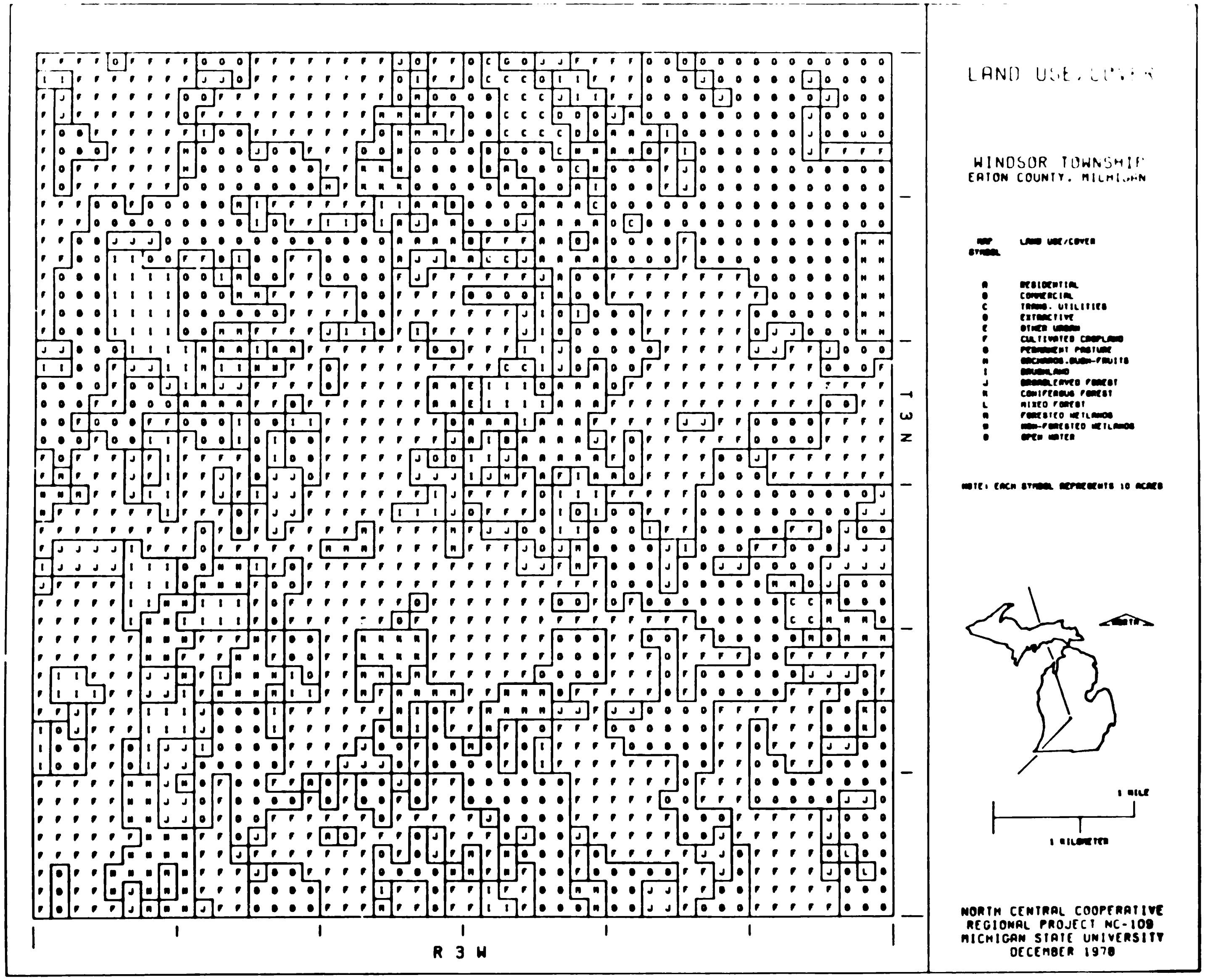
Local health codes, which are based on the siting requirements for conventional systems, have often served in many communities as "de facto zoning ordinances," commonly stricting development in many nonsewered rural areas (Butler, McCown, and Gates, 1977). This has allowed protection of significant environmental features, such as agricultural lands, forest lands, groundwater recharge areas, resource deposits, and wildlife habitat. With the realization that areas with slowly permeable, shallow, or wet soils can safely absorb sewage effluent, the argument for banning residential dwellings from these environmentally critical areas on health grounds becomes less convincing. Additional land use conflicts are almost sure to emerge from this type of situation.

An evaluation was made in Windsor Township to determine potential land use conflicts with the application of conventional and nonconventional on-site waste disposal systems. Figure 4-7 is a computer-generated land use cover map for the township from data gathered by interpreting color-infrared aerial photographs taken of the area during 1972. The minimum resolution of each area on the photograph was about 10 acres in size. Each symbol on the computer map then represents the dominant land use within each 10 acre cell. By visually comparing this generalized land use and cover map with Figure 4-6, it is evident that there are many potential land use conflicts between this non-agricultural use and current agricultural land in the township. In many instances, soils with excellent, good, or fair potential for home sewage disposal

Figure 4-7.--Computer-drawn interpretive map illustrating land use/cover in Windsor Township.


LAND USE/COVER
WINDSOR TOWNSHIP
EATON COUNTY, MICHIGAN
MAP SYMBOL
LAND USE/COVER
RESIDENTIAL
COMMERCIAL
TRANS. UTILITIES
EXTRACTIVE
OTHER URBAN
CULTIVATED CROPLAND
PERMANENT PASTURE
ORCHARDS, BUSH-FRUITS
BRUSHLAND
BROADLEAVED FOREST
CONIFEROUS FOREST
MIXED FOREST
FORESTED WETLANDS
NON-FORESTED WETLANDS
OPEN WATER
NOTE: EACH SYMBOL REPRESENTS 10 ACRES
1 MILE
1 KILOMETER
NORTH CENTRAL COOPERATIVE
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occur in agricultural areas. The most notable perhaps occurs in sections 7 and 18 (Figure 1-2) in the northwest quadrant of the township (Figure 4-6). Here soils with excellent, good, and fair potential occur in areas with cultivated cropland, broadleaved forest, permanent pasture, and brushlands. Several other areas scattered on the two maps show similar potential land use conflicts.

Residential Roads and Streets

The soil potential index (SPI) and potential rating of each mapping unit for residential streets and roads in Eaton County, Michigan, is shown in Table 4-5. The SPI ranges from a high of 100 for Bixby loam, 0 to 3 percent slopes, to a low of 1 for Palms muck. As shown in this table, all map units were also arrayed from excellent to poor potential according to their soil potential index. The class intervals generated by the JENKS computer program (see Table 3-8), which have the maximum goodness of variance fit (98.4%), were used to assign each mapping unit to one of the four qualitative rating classes indicating its relative potential for residential roads and streets in the county. Areas mapped as borrow land or water in the soil survey of the county were left unrated as shown in Table 4-5. Borrow land is a miscellaneous land type resulting from the excavation of materials, such as fill materials, gravel, or sand, to be used at another location. In the process of removing these materials, the original soil profile has been destroyed in these areas. All ratings must therefore

Table 4-5. Soil potential index and rating of soil mapping units for residential roads and streets in Eaton County, Michigan

Soil Potential Index	Soil Potential Rating	Soil Map Unit
100	Excellent	Bixby loam, 0 to 3 percent slopes
100	Excellent	Boyer loamy sand, 0 to 6 percent slopes
100	Excellent	Boyer sandy loams, 0 to 6 percent slopes
100	Excellent	Hillsdale sandy loam, 2 to 6 percent slopes
100	Excellent	Oshtemo sandy loam, 0 to 6 percent slopes
100	Excellent	Spinks loamy sand, 0 to 6 percent slopes
95	Excellent	Spinks-Metea loamy sands, 0 to 6 percent slopes
94	Excellent	Boyer loamy sands, 6 to 12 percent slopes
94	Excellent	Boyer sandy loams, 6 to 12 percent slopes
94	Excellent	Hillsdale sandy loam, 6 to 12 percent slopes
93	Excellent	Oshtemo sandy loam, 6 to 12 percent slopes
93	Excellent	Spinks loamy sand, 6 to 12 percent slopes
92	Excellent	Brady-Bronson sandy loams, 0 to 3 percent slopes
90	Good	Spinks-Metea loamy sands, 6 to 12 percent slopes
86	Good	Marlette loam, 2 to 6 percent slopes

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Table 4-5. Continued

Soil Potential Index	Soil Potential Rating	Soil Map Unit
86	Good	Matherton loam, 0 to 3 percent slopes
86	Good	Owosso-Marlette sandy loams, 1 to 6 percent slopes
86	Good	Wasepi sandy loam, 0 to 3 percent slopes
86	Good	Wasepi sandy loam, bedrock variant, 0 to 3 percent slopes
86	Good	Winneshiek silt loam, 0 to 3 percent slopes
85	Good	Boyer-Spinks loamy sands, 12 to 18 percent slopes
81	Good	Marlette loam, 6 to 12 percent slopes
81	Good	Marlette clay loam, 6 to 12 percent slopes, severely eroded
81	Good	Owosso-Marlette sandy loams, 6 to 12 percent slopes
78	Good	Capac-Marlette, 1 to 6 percent slopes
75	Fair	Parkhill loam
75	Fair	Sebewa loam
75	Fair	Colwood loam
75	Fair	Colwood loam, depressional
75	Fair	Gilford sandy loam
75	Fair	Lenawee silty clay loam, depressional
71	Fair	Marlette loam, 12 to 18 percent slopes

Table 4-5. Continued

Soil Potential Index	Soil Potential Rating	Soil Map Unit
71	Fair	Owosso-Marlette sandy loam, 12 to 18 percent slopes
70	Fair	Capac loam, 0 to 3 percent slopes
70	Fair	Kibbie fine sandy loam, 0 to 3 percent slopes
70	Fair	Metamora-Capac sandy loams, 0 to 4 percent slopes
70	Fair	Tuscola fine sandy loam, 0 to 4 percent slopes
60	Fair	Cohoctah fine sandy loam, frequently flooded
60	Fair	Shoals-Sloan loams
52	Poor	Marlette loam, 18 to 25 percent slopes
1	Poor	Adrian muck
1	Poor	Edwards muck
1	Poor	Houghton muck
1	Poor	Palms muck
-	Unrated	Borrow land
-	Unrated	Water

depend on an on-site investigation because of the highly variable nature of these units.

Corrective Measures and Continuing Limitations

In cooperation with officials at the Michigan Department of State Highways and Eaton County Road Commission, as well as pavement design engineers, local paving contractors, architects, designs for asphalt-paved residential roads and streets were identified for soils in Eaton County, Michigan. Appendix Table F2 lists soil features affecting the use, recommended designs to overcome these limitations, and a statement of the kinds of limitations remaining after these pavement designs are installed on these soils. As shown in this table, there are four kinds of construction measures or practices commonly used, either separately or together, on soils in the county to overcome problem soil conditions. These are the following: increase pavement thickness, excavate peat and muck, add fill to raise grade of roadway, or cutting and filling. A brief discussion of each is presented below.

(1) Increase pavement thickness.

Tye typical full-depth asphalt pavement structure for residential roads and streets consists of an asphalt surface course and one or more asphalt base courses placed directly on a properly compacted and prepared subgrade (Figure 4-8). "Hot-mix asphalt" is a term used by pavement design engineers to describe a hot-mixed asphaltic mixture composed of graded aggregate bounded together by asphalt (Michigan Asphalt Paving Association, 1977).

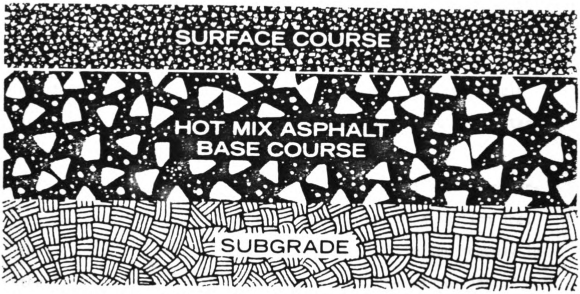

Figure 4-8.--Typical full-depth asphalt pavement cross-section for residential roads and streets.

SOURCE: National Asphalt Pavement Association, 1975.

Research conducted over a number of years at different locations in the United States indicates that subbases and cushion courses composed of stone or gravel are not required with full-depth asphalt pavement (Brakey and Carroll, 1971; Beagle, 1974). In fact, these type of granular materials are detrimental in that they will collect water and distribute it over an entire subgrade, thereby allowing underground water to penetrate the pavement. Since asphalt surfaces and bases are themselves unaffected by moisture and frost, a well designed asphalt pavement can result in a waterproof section which will be a barrier to subsoil water, minimizing the damaging effects of frost.

The principal factors that should be considered in determining the overall thickness of an asphalt pavement section are: the estimated numbers and types of vehicles to use the roadway in the future, the support of the subgrade, and the properties of materials in the pavement structure. After gathering many years of test data, the design approach developed by the Asphalt Institute makers use of thickness design charts to determine the total thickness of hot-mix asphalt pavement required for given traffic and subgrade conditions (Asphalt Institute, 1970). Table 4-6 shows the typical thickness of asphalt pavements used for residential roads and streets in Michigan based on the load-supporting characteristics of subgrade soils. The design thickness for any given soil can then be determined by evaluating its load supporting characteristics, commonly measured by the California Bearing Ratio (CBR) test. Excellent subgrade soils will have a CBR value of 10

Table 4-6. Typical thickness of full-depth asphalt pavements by subgrade class for residential roads and streets in Michigan.

Subgrade Class	Surface Course	Hot-Mix Asphalt Base	Total Thickness
Excellent	1.0[1]	4.0	5.0
Good	1.5	5.0	6.5
Poor	1.5	6.5	8.0

[1]All thicknesses in inches.

SOURCE: Michigan Asphalt Paving Association, Design and Construction Guide, 1977.

or more, good subgrade soils will have a CBR value of 6 to 10, and poor subgrade soils will have a CBR value of only 3 to 6 (Michigan Asphalt Paving Association, 1977).

Each soil in Eaton County was assigned to one of these three subgrade categories with the assistance of experienced soils engineers located in the immediate area. Since laboratory test data were unavailable, the approximate correlation of the AASHTO[16] and Unified Soil Classification systems with the CBR was then used to estimate CBR values from the AASHTO and Unified ratings for each soil. These values assured proper placement of each soil in one of the three subgrade classes. Based on the information provided then in Table 4-6, excellent subgrade soils (e.g., Bixby and Boyer soils) would only require a "normal" asphalt pavement total thickness of 5 inches, while another offering poor subgrade support (e.g., Capac and Kibbie soils) would require an increased total thickness of 8 inches.

(2) Excavate peat and muck.

The treatment of peat and muck soils essentially involves either the total or partial excavation of these unstable organic materials. They make unsuitable subgrades for residential roads and streets being highly compressive and subject to severe frost action. Roads built on these soils often exhibit uneven and long-continued settlement of the roadway grade line. If the road alignment must cross these materials, the Michigan Department of

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[16]System adopted by the American Association of State Highway and Transportation Officials.

State Highways recommends that they should be excavated down to their mineral horizons, provided this can be accomplished satisfactorily with conventional equipment (Michigan Department of State Highways, 1970). The excavated material is then replaced by suitable borrow to an elevation 2 feet or more above the original soil surface before compaction of the grade material. As a general rule, 12 to 15 feet is commonly the maximum depth for excavation with conventional equipment. Deeper deposits of peat and muck soils require special treatment. The reader is referred to the Field Manual of Soil Engineering, published by the Michigan Department of State Highways, for an excellent discussion of the practices and techniques required for constructing roads on organic soils.

(3) Add fill to raise grade above water table.

In general, areas that have a seasonally high water table or are depressional will require elevation of grade. Good drainage is of critical importance in the design and construction of asphalt pavements. The accumulation of excess water in the underlying subgrade soils can cause eventual damage to the pavement structure. If this soil becomes wholly or partially saturated it will lose stability and support weakening the entire overlying pavement structure. The roadway would then be susceptible to breakup under imposed traffic loads. In soil areas with seasonally high water tables, the recommended practice of highway engineers is to raise the grade of the roadway with granular materials to provide a separation between the asphalt pavement and the groundwater to cut off capillary rise. A common rule of thumb used by these engineers is to establish the grade line at least four feet above the yearly maximum ground water table (Asphalt Institute, 1966).

(4) Cutting and filling.

Residential roads and streets should be as flat as possible to permit automobiles and commercial vehicles to ascend or descend with ease at a constant speed. Although those with steep grades provide interesting scenic views of the surrounding countryside, they are, in general, tiring for pedestrians, bikes, and automobiles (Untermann, 1978). They can also be unsafe since descending commercial vehicles must use their brakes on grades of more than about 4 or 5 percent. This can pose a safety problem on wet or icy pavements. Keeping this in mind, public agencies which regulate the construction of residential thoroughfares have commonly set upper limits for the maximum grade of any road or street. For example, the Eaton County Road Commission, in its regulations pertaining to subdivision of lands, requires that the maximum grade of any street be no greater than 5 percent in the county (Eaton County Road Commission, 1968).

To construct roads and streets with these gradients, requires some grading of soil materials to adjust the road alignment to the existing topography. Grading of soil materials consists of essentially two basic operations: removing soil material (called cutting) and adding soil material (called filling). Roads can be laid out at angles to or perpendicular to the contour. The former may require extensive amounts of grading, but is preferable because it results in a route that can move motorized vehicles gradually up or down or around a hill (Untermann, 1978). By balancing cut-and-fill operations, grading costs can be minimized because there will be little need to import or export soil materials. As in any earthmoving operation, however, disturbed areas on the roadway right-of-way must be seeded and mulched and vegetation maintained to prevent excessive soil losses due to erosion. Maintenance costs for these practices can be expected to be greater as slope gradients increase.

Cost of Corrective Measures

Table 4-7 presents the estimated costs of applying different corrective measures to overcome soil limitations for residential roads and streets in Eaton County, Michigan. Note that these are only estimates in 1978 dollars of the costs per linear foot of roadway required to install corrective measures on 30-foot wide roads. They are not intended to eliminate the need for cost estimating by local contractors on a site-by-site basis. The dollar figure listed in Table 4-7 for each soil is the mean of the range in costs (Appendix Table C2) for installing the different corrective measures. These were computed from cost analyses of previously completed road and street projects obtained from local asphalt pavers, home builders, and the county road commission, as well as other sources in the study area.

Table 4-7. Soil limitation and estimated cost of applying different corrective measures for residential roads and streets in Eaton County, Michigan.

Soil Map Unit	Soil Limitation	Initial cost per Linear Foot[1] (1978)	Corrective Measure
Adrian muck	Severe	44.50	A,C.D
Bixby loam, 0 to 3 percent slopes	Moderate	15.50	A
Borrow land	Properties too variable to be rated		
Boyer loamy sand, 0 to 6 percent slopes	Moderate	15.50	A
Boyer loamy sand, 6 to 12 percent slopes	Moderate	17.00	A,E
Boyer sandy loams, 0 to 6 percent slopes	Moderate	15.50	A
Boyer sandy loams, 6 to 12 percent slopes	Moderate	17.00	A,E
Boyer-Spinks loamy sands, 12 to 18 percent slopes	Severe	20.00	A,E
For Spinks part see Spinks series			
Brady-Bronson sandy loams, 0 to 3 percent slopes	Severe	19.50	B
For Bronson part see Bronson series			
Bronson series	Severe	15.50	A
Mapped only in a complex with Brady soils			
Capac loam, 0 to 3 percent slopes	Severe	24.00	B
Capac-Marlette loams, 1 to 6 percent slopes	Severe	24.00	B
For Marlette part see Marlette series			
Cohoctah fine sandy loam, frequently flooded	Severe	23.50	A,D
Colwood loam	Severe	23.50	A,D
Colwood loam, depressional	Severe	23.50	A,D
Edwards muck	Severe	44.50	A,C.D
Gilford sandy loam	Severe	23.50	A,D

Table 4-7. Continued

Soil Map Unit	Soil Limitation	Initial cost per Linear Foot[1] (1978)	Corrective Measure
Hillsdale sandy loam, 2 to 6 percent slopes	Moderate	15.50	A
Hillsdale sandy loam, 6 to 12 percent slopes	Moderate	17.00	A,E
Houghton muck	Severe	44.50	A,C.D
Kibbie fine sandy loam, 0 to 3 percent slopes	Severe	24.00	B
Lenawee silty clay loam, depressional	Severe	23.50	A,D
Marlette loam, 2 to 6 percent slopes	Moderate	19.50	B
Marlette loam, 6 to 12 percent slopes	Moderate	21.00	B,E
Marlette clay loam, 6 to 12 percent, severely eroded	Moderate	21.00	B,E
Marlette loam, 12 to 18 percent slopes	Severe	24.00	B,E
Marlette loam, 18 to 25 percent slopes	Severe	30.00	B,E
Matherton loam, 0 to 3 percent slopes	Severe	19.50	B
Metamora-Capac sandy loam, 0 to 4 percent slopes	Severe	24.00	B
For Capac part see Capac series			
Metea			
Mapped only in complex with Spinks soils			
Metea part of Spinks Metea loamy sands, 0 to 6 percent slopes	Moderate	19.50	B
Metea part of Spinks-Metea loamy sands, 6 to 12 percent slopes	Moderate	21.50	B.E
Oshtemo sandy loam, 0 to 6 percent slopes	Slight	15.50	A
Oshtemo sandy loam, 6 to 12 percent slopes	Moderate	17.50	A.E

Table 4-7. Continued

Soil Map Unit	Soil Limitation	Initial cost per Linear Foot[1] (1978)	Corrective Measure
Owosso-Marlette sandy loams, 1 to 6 percent slopes	Moderate	17.50	B
For Marlette part see Marlette series			
Owosso-Marlette sandy loams, 6 to 12 percent slopes	Moderate	19.50	B,E
For Marlette part see Marlette series			
Owosso-Marlette sandy loams, 12 to 18 percent slopes	Severe	24.00	B,E
For Marlette part see Marlette series			
Palms muck	Severe	44.50	A,C,D
Parkhill loam	Severe	23.50	A,D
Sebewa loam	Severe	23.50	A,D
Shoals-Sloan loams	Severe	23.50	A,D
For Sloan part see Sloan series			
Sloan Series	Severe	23.50	A,D
Mapped only in complex with Shoals series			
Spinks loamy sand, 0 to 6 percent slopes	Slight	15.50	A
Spinks-Metea loamy sands, 0 to 6 percent slopes	Slight	15.50	A
For Metea part see Metea series			
Spinks loamy sand, 6 to 12 percent slopes	Moderate	17.50	A,E
Spinks-Metea loamy sands, 6 to 12 percent slopes	Moderate	17.50	A,E
For Metea part see Metea series			
Spinks part of Boyer-Spinks loamy sands, 12 to 18 percent slopes	Severe	20.00	A,E

Table 4-7. Continued

Soil Map Unit	Soil Limitation	Initial cost per Linear Foot[1] (1978)	Corrective Measure
Tuscola fine sandy loam, 0 to 4 percent slopes	Severe	24.00	B
Wasepi sandy loam, 0 to 3 percent slopes	Severe	19.50	B
Wasepi sandy loam, bedrock variant, 0 to 3 percent slopes	Severe	19.50	B
Winneshiek silt loam, 0 to 3 percent slopes	Moderate	19.50	B

[1]Roadway thirty feet wide.

A = Normal thickness of full depth pavement
B = Increased thickness of full depth pavement
C = Excavate peat and muck
D = Add fill to raise grade
E = Cuts and fills

The average initial costs for installing corrective measures on different soils for roads and streets in Eaton County ranges from \$15.50 to \$44.50 per linear foot of roadway (Table 4-7). Further study of the data presented in this table reveals that the organic soils (i.e., Adrian, Edwards, Houghton, and Palms) have the highest costs (44.50) for road construction among all the units mapped in the county. In fact, their costs are nearly twice as much as those of the most costly mineral soils for road construction (i.e., Capac loam at \$24.00 and Marlette loam 18 to 25 percent slopes at \$30.00). The additional costs for overcoming their severe soil limitations are indeed quite high compared to those of mineral soils. This vividly illustrates the reason why organic soils should be avoided for residential road and street construction, if at all possible.

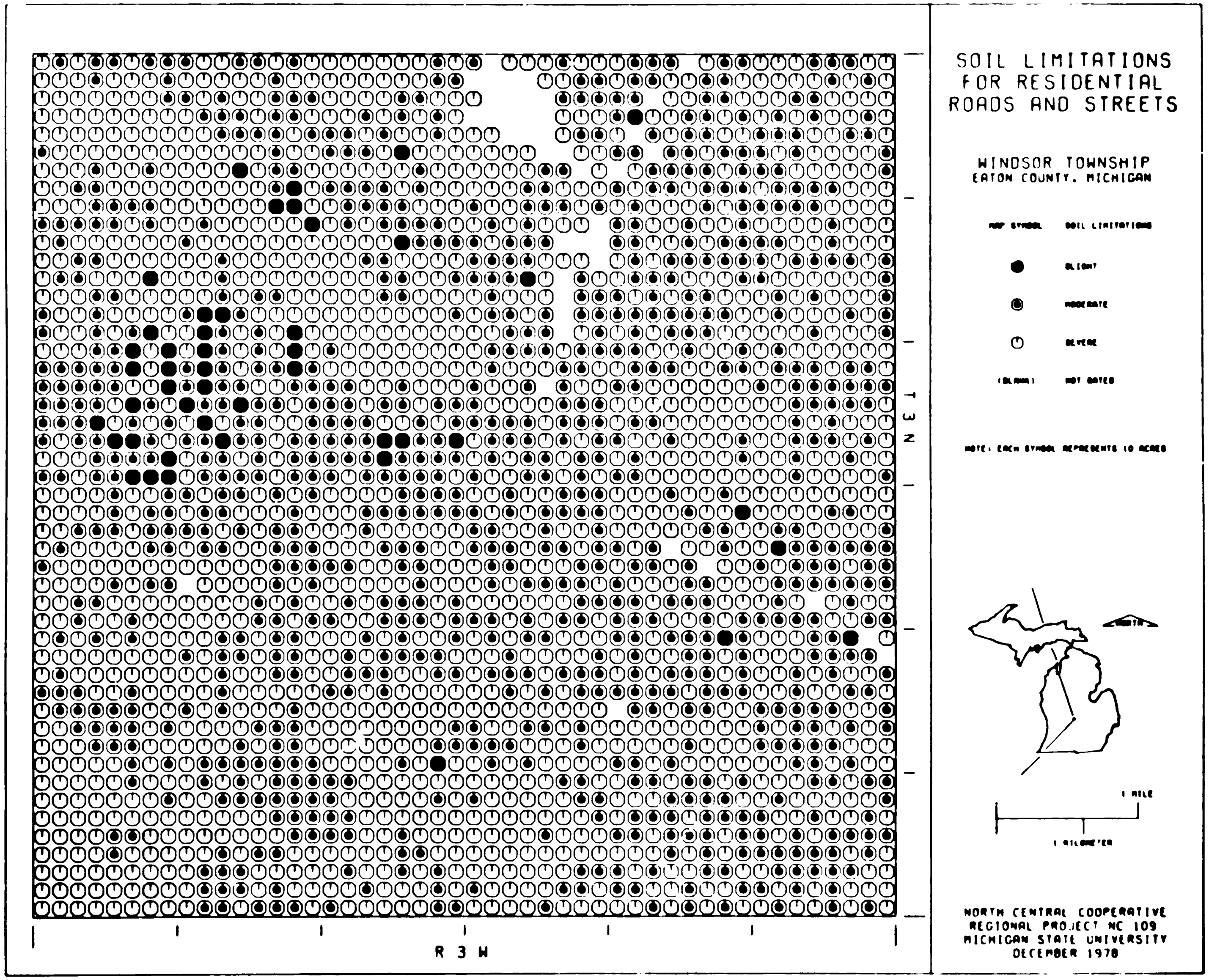
Table 4-7 also shows the increased costs of residential road construction on sloping soils. In the case of the Marlette series, for example, there is approximately a 54 percent increase (\$30.00 versus \$19.50) in the cost of constructing a road on a Marlette map unit with an "E" slope (18 to 25 percent) compared to that on a "B" slope (2 to 6 percent). This increase in construction cost is due mainly because of the enormous volume of soil material that must be moved in order to provide a suitable road grade. The additional cutting and filling operation obviously requires an increase in manpower and machinery. As in the case of organic soils, the data compiled in this study indicates that steeply sloping soils should be similarly avoided for residential road construction, if at all possible.

Computer Output

Figure 4-9 illustrates the locations of cells with soil limitations for residential roads and streets in Eaton County. The basic format of this computer-generated plotter map is similar to those previously discussed in this chapter. The darker octagons on the map represent areas which have fewer limitations for roads and streets than those areas represented by lighter-shaded octagons. The areas with blank cells are either borrow land or water and are unrated for this purpose.

By visually inspecting the map it is apparent that much of the land in the township has severe limitations for residential roads and streets. Most predominant is the area in the vicinity of the "Old Maid Swamp" (see Figure 1-3) in the northeast portion of the township (Figure 4-9). As previously mentioned, this area has nearly level, poorly and very poorly drained, mucky and loamy soils (i.e., Adrian, Colwood, Edwards, Gilford, Houghton, Palms, Parkhill, etc.) located in depressions and drainageways on the landscape. Another area on the map with similarly rated soils is located in the extreme southwest corner of the township (Figure 4-9). A study of the soils map, sheet 35, for the county, indicates that this area's landscape is dominated by the Capac, Gilford, Houghton, and Sebewa series. Soils in these two areas present serious problems in the construction of residential roads and

Figure 4-9.--Computer-drawn interpretive map illustrating soil limitations for residential roads and streets in Windsor Township.


SOIL LIMITATIONS
FOR RESIDENTIAL
ROADS AND STREETS
WINDSOR TOWNSHIP
EATON COUNTY, MICHIGAN
MAP SYMBOL
SOIL LIMITATIONS
SLIGHT
MODERATE
SEVERE
(BLANK)
NOT RATED
NOTE: EACH SYMBOL REPRESENTS 10 ACRES
NORTH
1 MILE
1 KILOMETER
NORTH CENTRAL COOPERATIVE
REGIONAL PROJECT NC 109
MICHIGAN STATE UNIVERSITY
DECEMBER 1978
T 3 N
R 3 W

streets, although the organic soils of this group (Adrian, Edwards, Houghton, Palms) have considerably more difficult soil limitations to overcome requiring additional corrective measures, thereby dramatically increasing the cost of residential road construction.

Soils that present only slight limitations for residential road construction are almost exclusively concentrated in the west-central portion of the township (Figure 4-9) adjacent to U.S. Highway 27 (Temporary Interstate 69) and in the vicinity of West Windsor (Figure 1-2). Other soil areas with slight limitations are scattered throughout the map, but without any recognizable pattern and with limited areal extent.

Table 4-8 shows the proportionate extent and approximate acreage of soils in Windsor Township with different degrees of limitations for residential roads and streets. The calculations are based on the number of cells in each category (slight, moderate, severe, or unrated) as plotted on Figure 4-9. According to the information presented at the right side in this table, 461, 9,308, and 12,856 acres have slight, moderate and severe limitations for residential roads and streets in Windsor Township, respectively. This total acreage accounts for 98.2 percent of the land area in the township (22,625 acres); the remaining acreage (415) is water and borrow land which is unrated for this purpose in the county. These data indicate that only 42.4 percent of the land (9,769 acres) in the township has slight or moderate limitations for residential roads and streets, and is therefore suitable for

Table 4-8. Proportionate extent and approximate acreage of soils classified by soil limitations and potentials for residential roads and streets in Windsor Township, Eaton County, Michigan

Degree of Soil Limitation	Soil Potential Rating								Unrated		Total	
	Excellent		Good		Fair		Poor					
	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres
Slight	2.0	461	-	-	-	-	-	-	-	-	2.0	461
Moderate	3.3	760	37.1	8548	-	-	-	-	-	-	40.4	9308
Severe	0.8	184	4.5	1037	41.4	9539	9.1	2096	-	-	55.8	12856
Unrated	-	-	-	-	-	-	-	-	1.8	415	1.8	415
Total	6.1	1405	41.6	9585	41.4	9539	9.1	2096	1.8	415	100.0	23040

NOTE: Calculations are based on Figure 4-9 and 4-10 (2304 cells, 10 acres per cell).

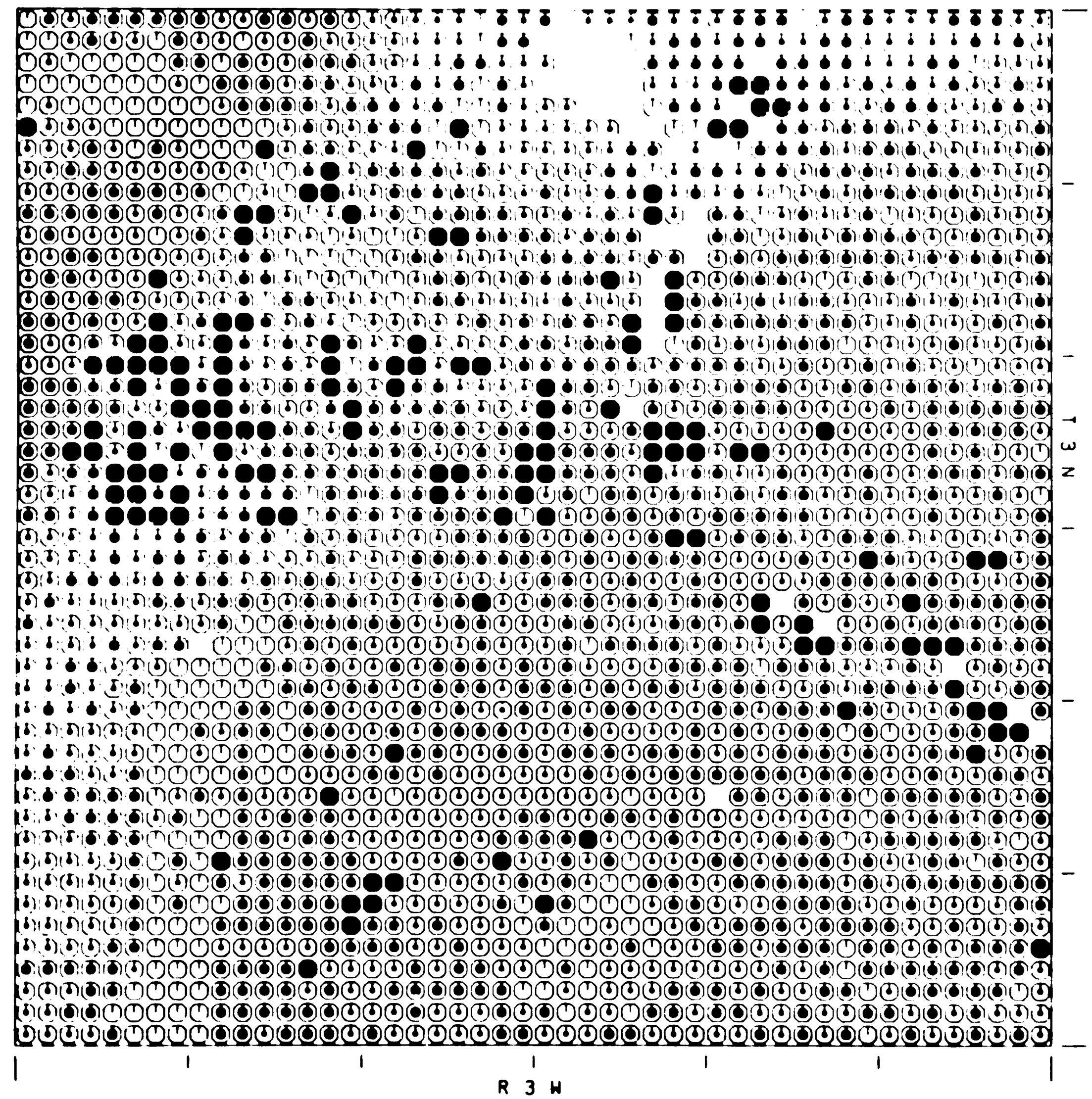
use without special road designs, while more than half of the land area (55.6 percent or 12,856 acres) has severe soil limitations for these same land uses, usually requiring more costly corrective measures.

Significant changes can occur, however, in the amount of suitable land for residential roads and streets by applying different corrective measures on soils with moderate or severe limitations. Table 4-8 shows the proportionate extent and approximate acreage of soils in Windsor Township classified according to their potential for residential streets and roads. According to the information presented along the bottom of the table, 1,405, 9,585, 9,539 and 2,096 acres have excellent, good, fair, and poor potential, respectively, for this land use. Further study of these data reveals that out of the 12,856 acres of land in the township, which are rated as having severe soil limitations for residential roads and streets, 83.7 percent has excellent, good, or fair potential for residential roads and streets. This is a significant increase of 111 percent or 10,760 acres in the amount of land that might be suitable for these land uses in the township, provided that the proper corrective measures are applied to each soil (Appendix Table F2). Even more significant is the fact that only 9.1 percent of the land area in the township has soils with poor potential for this land use because their soil limitations are extremely difficult and costly to overcome with different corrective measures.

Figure 4-10 shows the locations of soils with different potentials for residential roads and streets in Windsor Township. Three areas on the map stand out by having high concentrations of soils with excellent or good potential for such uses. The most significant perhaps is the area in the northwest quadrant of the township and located almost entirely in sections 17 and 18 (Figure 1-2). By visually inspecting this map, it is apparent that of the two, section 18 has the greatest number of cells with soils having excellent or good potential ratings. In fact, only one cell in the entire section has poor soil potential for residential roads and streets. A second such area on the map is located almost at the center of the township, in close proximity to the corporate boundary of the Village of Dimondale (Figure 1-2). A third such area, located in the southern portion of the township and east of the King and Carleton Drains (Figure 1-3), also has a favorable distribution of soils with excellent or good potential for this land use. Immediately west of this area on the map is a large number of contiguous cells which have predominantly poor potential for residential streets and roads.

As in the case of on-site waste disposal systems, the best soils in the township for residential streets and roads commonly occur in areas presently used by agriculture. By visually comparing the generalized land use map for the township (Figure 4-7) with Figure 4-10, it is evident that the most notable example of this potential land use conflict again occurs in sections 7 and 18

Figure 4-10.--Computer-drawn interpretive map illustrating soil potential for residential roads and streets in Windsor Township.



SOIL POTENTIAL FOR RESIDENTIAL ROADS AND STREETS

WINDSOR TOWNSHIP
EATON COUNTY, MICHIGAN

MAP SYMBOL	SOIL POTENTIAL
●	EXCELLENT
◉	GOOD
◐	FAIR
◯	POOR
(BLANK)	NOT RATED

NOTE: EACH SYMBOL REPRESENTS 10 ACRES

1 MILE

1 KILOMETER

NORTH CENTRAL COOPERATIVE
REGIONAL PROJECT N. 129
MICHIGAN STATE UNIVERSITY
DECEMBER 1978

(Figure 1-2) in the northwest quadrant of the township. Here soils with excellent, good, and fair potential occur in areas with cultivated cropland, broadleaved forest, permanent pasture, or brushlands.

Residential Dwellings with Sanitary Sewers and Basements

The soil potential index (SPI) and potential rating of each mapping unit for residential dwellings with basements in Eaton County, Michigan is shown in Table 4-9. The SPI ranges from a high of 100 for Bixby loam, 0 to 3 percent slopes, to a low of 1 for Palms muck. As shown in this table, all map units were also arrayed from excellent to poor potential according to their soil potential index. The class intervals generated by the JENKS computer program (see Table 3-8), with the maximum goodness of variance fit (97.5%), were used to assign each mapping unit to one of the four qualitative rating classes indicating its relative potential for residential dwellings in the county. Note that the areas mapped as water and borrow land were again left unrated, as presiouvly discussed.

Corrective Measures and Continuing Limitations

In cooperation with private home builders and home construction trade organizations, as well as local engineers and architects, designs for residential dwellings with basements serviced with sanitary sewers were identified for soils in Eaton County, Michigan. Appendix Table F3 lists the features affecting

Table 4-9. Soil potential index and rating of soil mapping units for residential dwellings with sanitary sewers and basements in Eaton County, Michigan.

Soil Potential Index	Rating	Soil Map Unit
100	Excellent	Bixby loam, 0 to 3 percent slopes
100	Excellent	Boyer loamy sand, 0 to 6 percent slopes
100	Excellent	Boyer sandy loams, 0 to 6 percent slopes
100	Excellent	Hillsdale sandy loam, 2 to 6 percent slopes
100	Excellent	Marlette loam, 2 to 6 percent slopes
100	Excellent	Oshtemo sandy loam, 0 to 6 percent slopes
100	Excellent	Owosso-Marlette sandy loams, 1 to 6 percent slopes
100	Excellent	Spinks loamy sand, 0 to 6 percent slopes
100	Excellent	Spinks-Metea loamy sands, 0 to 6 percent slopes
91	Excellent	Oshtemo sandy loam, 6 to 12 percent slopes
91	Excellent	Spinks loamy sand, 6 to 12 percent slopes
91	Excellent	Spinks-Metea loamy sands, 6 to 12 percent slopes
91	Excellent	Boyer sandy loams, 6 to 12 percent slopes
91	Excellent	Boyer loamy sands, 6 to 12 percent slopes
91	Excellent	Hillsdale sandy loam, 6 to 12 percent slopes

Table 4-9. Continued

Soil Potential Index	Rating	Soil Map Unit
91	Excellent	Marlette loam, 6 to 12 percent slopes
91	Excellent	Marlette clay loam, 6 to 12 percent slopes, severely eroded
91	Excellent	Owosso-Marlette sandy loams, 6 to 12 percent slopes
86	Excellent	Capac-Marlette loams, 1 to 6 percent slopes
73	Good	Brady-Bronson sandy loams, 0 to 3 percent slopes
73	Good	Capac loam, 0 to 3 percent slopes
73	Good	Kibbie fine sandy loam, 0 to 3 percent slopes
73	Good	Matherton loam, 0 to 3 percent slopes
73	Good	Marlette loam, 12 to 18 percent slopes
73	Good	Metamora-Capac sandy loams, 0 to 4 percent slopes
73	Good	Owosso-Marlette sandy loams, 12 to 18 percent slopes
73	Good	Tuscola fine sandy loam, 0 to 4 percent slopes
73	Good	Wasepi sandy loam, 0 to 3 percent slopes
73	Good	Winneshiek silt loam, 0 to 3 percent slopes
73	Good	Boyer-Spinks loamy sands, 12 to 18 percent slopes

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Table 4-9. Continued

Soil Potential Index	Rating	Soil Map Unit
58	Fair	Marlette loam, 18 to 25 percent slopes
58	Fair	Wasepi sandy loam, bedrock variant, 0 to 3 percent slopes
27	Fair	Colwood loam
27	Fair	Colwood loam, depressional
27	Fair	Gilford sandy loam
27	Fair	Lenawee silty clay loam, depressional
27	Fair	Parkhill loam
27	Fair	Sebewa loam
20	Poor	Cohoctah fine sandy loam, frequently flooded
20	Poor	Shoals-Sloan loams
1	Poor	Adrian muck
1	Poor	Edwards muck
1	Poor	Houghton muck
1	Poor	Palms muck
-	Unrated	Borrow land
-	Unrated	Water

the use, recommended designs to overcome these limitations, and limitations remaining after foundations are installed on these soils. As shown in this table, there are six kinds of corrective measures commonly used, either separately or concurrently, on soils in the county to overcome problem soil conditions. These are the following: alternative basement construction design, add fill to raise grade of site, excavate rock, excavate peat and muck, cuts and fills, or improve surface drainage. A brief discussion of each is presented below.

(1) Alternative basement construction design.

A watertight basement is necessary to provide a dry and useable space for recreation rooms, workshops, or service areas, and storage rooms for valuable household articles. If water penetrates the walls or ground slab of a basement, this space may become damp and musty making it relatively useless for such purposes. Basements need not be damp or leaky. If either condition exists, it is probably because proper drainage and foundation design was overlooked when the house was built.[17] Although there are remedial measures commercially available for repairing damp or leaky basements, it is obviously much easier and more economical to make a basement watertight when constructed than to correct a leaky one.

Home builders use many and varied techniques to prevent basement leakage depending upon soil and site conditions. The

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[17]Personal communication with Donald Carr, Staff Engineer, National Association of Home Builders, Washington, D.C.

conventional basement construction design commonly has a fair amount of waterproofing, such as an asphalt membrane on the basement walls, a thick polyethylene film under the slab, drainage tile around the building, and a sump system (National Association of Home Builders, 1966). The floor slab is usually about 4 inches thick placed over a 4 inch bed of gravel, and maybe lightly reinforced with welded-wire fabric. The basement walls typically consist of structurally plain concrete without reinforcement for hydrostatic pressure or concrete shrinkage.

In site locations where the foundation is subjected to a seasonally high ground water table, additional waterproofing practices are required to protect basements against water infiltration. There are basically two alternative systems commonly used by builders for waterproofing residential basements. The choice of either system is dependent to a large degree upon the magnitude of the soil water problem.

The first alternative foundation system has a design very similar to that used in conventional basement construction (Figure 4-11). This system is referred to as "drained" because it allows infiltrating water to move through the underdrain gravel beneath the slab and collect at a drainage sump where it is subsequently pumped out of the basement. Its basement walls are horizontally and vertically reinforced throughout to withstand hydrostatic pressure. Weepholes are placed in the footing to allow water collected outside the wall to flow towards the sump. The basement walls are also protected in this design from water seepage through applications of polyethylene plastic film (Figure 4-11) instead of only asphalt parging used in the conventional design. It is generally believed that the polyethylene improves the wall's impermeability and can adjust to future wall cracking when properly installed (National Association of Home Builders Research Foundation, 1977). To complete this waterproofing process, wall penetrations, such as sewer lines and water pipes, are properly sealed to prevent water seepage.

This type of foundation design is adaptable to sites where the inflow of water from the surrounding soil is within the capacity of the sump to adequately remove this water. Proper maintenance of the electric sump pump is therefore an absolute necessity in order to prevent flooding of these basements. The costs to maintain and run these systems is clearly a continuing limitation.

Where the soil water inflow is beyond the capacity of a sump in the drained system, an alternative "undrained" or barge foundation design is required (Figure 4-12). Its basement walls and floor slab are designed to be watertight like the hull of a barge (National Association of Home Builders Research Foundation, 1977). They are wrapped in a complete waterproofing envelope made up of asphalt, rubber, neoprene, polyvinyl chloride, and polyethylene film. The walls and slab are both structurally strengthened throughout to resist the anticipated upward hydrostatic pressure from beneath the slab. Special care is taken in this construction

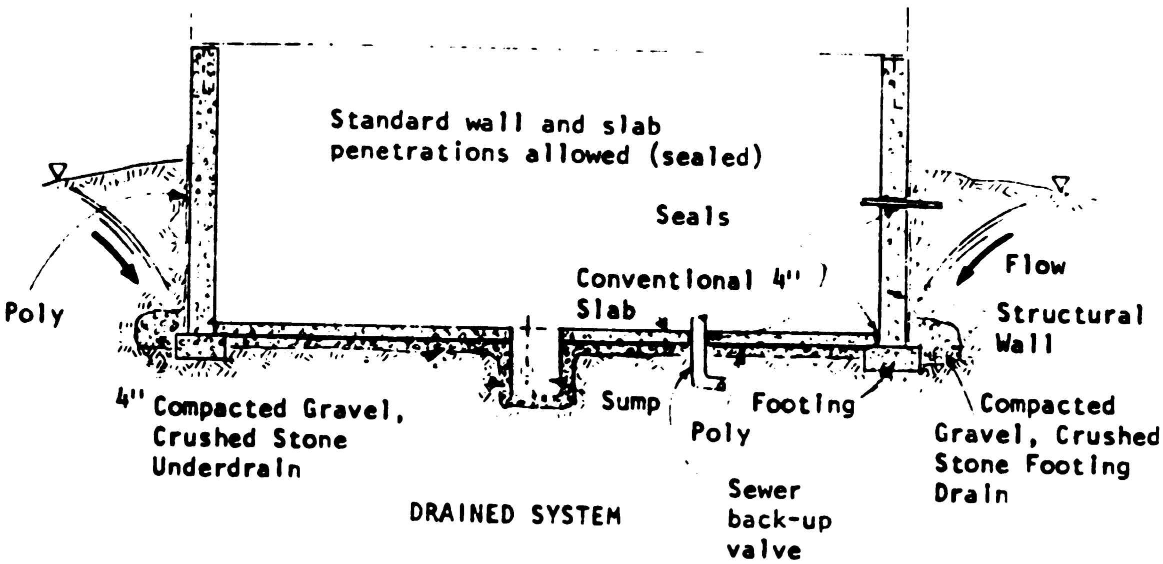

Figure 4-11.--Drained basement design system.

SOURCE: National Association of Home Builders Research Foundation, 1977.

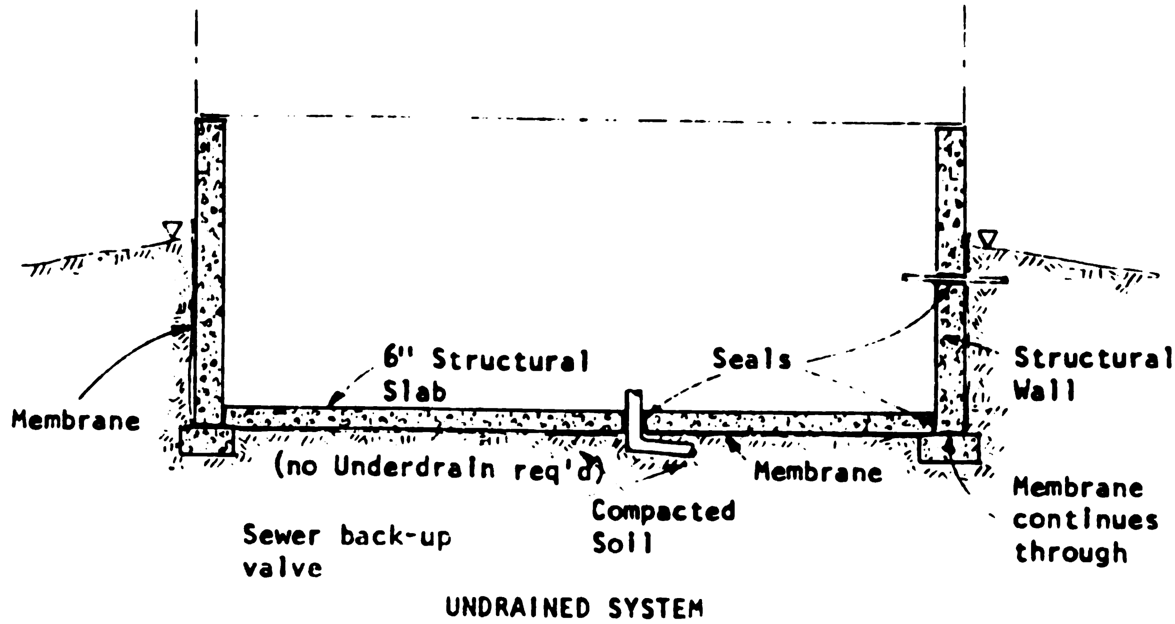

Figure 4-12.--Undrained basement design system.

SOURCE: National Association of Home Builders Research Foundation, 1977.

design to insure that all joints and penetrations, such as pipes or conduits, are permanently sealed. In addition, there is continual inspection on-site to insure that there has been no penetration or puncture of the foundation's waterproof membrane during construction or backfilling.

(2) Add fill to raise grade of site.

Fills are commonly used by home builders to raise the existing grade of building sites located in depressions or low-lying areas. Once properly compacted and tested, these fills can support foundations with safety and only nominal settlement. This is one of the least expensive methods available to elevate the lowest floor (including the basement) of a residence to or above the base floor level (100-year flood) as indicated on a flood insurance rate map (Federal Insurance Administration, HUD, 1977). It is not the intent of this investigator to suggest that dwellings with basements should be built in floodprone areas, but rather where such construction may be appropriate, and not prohibited by law or regulation,[18] flood losses to these dwellings constructed above flood levels can be minimized or eliminated. Although property damage may be minimized by raising the grade of the dwelling above base flood heights, its accessibility can still be restricted and yard use be eliminated during periods of prolonged flooding.

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[18]Communities participating in the National Flood Insurance Program may prohibit building in the floodplain area unless it can be demonstrated that the proposed use will not increase the water surface elevation of the base flood more than one foot at any point.

(3) Excavate rock.

The treatment of soils shallow to bedrock commonly requires excavation of the rock material down to the proposed footing depths for the dwelling foundations. The kind of special equipment required to excavate this material depends upon the type of bedrock encountered and its relative hardness. Rippable bedrock can be excavated with a single-tooth ripping attachment on a 200-horsepower tractor, while hard bedrock generally requires blasting with dynamite (Olson, Witty and Marshall, 1969). Whatever the method used to excavate this bedrock, the resulting spoil materials must then be loaded onto dump trucks and hauled from the site. These operations increase construction costs considerably although rock, especially if it extends under the dwelling foundation, makes an excellent foundation bed since it has an extremely high bearing capacity.

(4) Excavate peat and muck.

Peat and muck soils make unsuitable subgrade materials for dwelling foundations since they are highly compressible and have low bearing strength (Tilmann and Mokma, 1976). Dwellings built on these soils often show long-continued uneven settlement and eventual foundation cracking (Slusher, Cockaham and Mattews, 1974). This is bothersome to the homeowner and costly repairs may be needed because of this long-term settlement. Where single-family dwellings are constructed on sites consisting of organic soils, the common practice to overcome these difficulties is to excavate down to their mineral horizons and replace these materials by suitably compacted borrow to the normal level of the foundation footing common for the area.[19] This will provide firm support for the foundation footings. As in the case of rock excavation, these processes can increase construction costs substantially.

(5) Cutting and filling.

Land grading is common to practically all residential construction sites since these dwellings generally require a fairly level pad to sit on (Untermann, 1978). As in the case of residential road construction, the grading process for dwellings is similarly a two step process: cutting (removing soil materials) and filling (adding soil materials). With the size and quality of modern earth-moving machines and improved grading designs, there is almost no physical limit to the amount of earth-moving that can be accomplished. Yet, as slope gradient increases, the shear volume of material that must be moved in order to level the excavation site increases geometrically, as do construction costs and soil and water control problems (Urban Land Institute, 1978).

All grading causes erosion to a certain degree. Wherever possible steeply sloping sites and critically erodible soils should therefore be left undisturbed, or disturbed areas kept as small as possible to minimize soil losses. Those that are disturbed should be treated as soon as possible with adequate soil erosion

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[19] Personal communication with Donald Carr, Staff Engineer, National Association of Home Builders, Washington, D.C.

control measures (i.e., mulching, seeding, sodding, etc.)[20] and to retain sediment on-site. Maintenance costs for these practices can be expected to be greater as slope gradients increase.

(6) Improve drainage.

Wet soils, unless drained, provide poor conditions for the establishment of lawns and trafficability of these yard areas for residential dwellings with basements. To overcome this wetness limitation, these soils commonly require a system of subsurface drainage, in addition to adequate surface drains, to collect and dispose of the free water from the soil. Conduits, such as agricultural drain tile, plastic pipe, or tubing, are installed beneath the soil surface. Water enters these plastic pipes through a series of holes, commonly facing downward, and then flows by gravity to an outlet. A typical system will have several laterals connected to a main line. These systems require maintenance or upkeep since frost action and equipment travel may dislodge sections of pipe and reduce efficiency of operation.

Cost of Corrective Measures

Table 4-10 presents the estimated costs of applying different corrective measures to overcome soil limitations for residential dwellings with basements in Eaton County, Michigan. The figures

[20]In Michigan, these must be identified in an erosion control plan to meet the requirements of Michigan's Public Act 347 of 1972, commonly known as the "Soil Erosion and Sediment Control Act," and its corresponding General Rules promulgated under the act. Standards and specifications for different erosion control measures are usually available at Soil Conservation District Offices.

Table 4-10. Soil limitations and estimated costs of applying different corrective measures for residential dwellings with basements in Eaton County, Michigan

Soil Map Unit	Soil Limitation	Initial Cost per Dwelling Site ($1978)	Corrective Measures
Adrian muck	Severe	9700	C,D,F,H
Bixby loam, 0 to 3 percent slopes	Slight	5200	A
Borrow land	Properties to variable to be rated		
Boyer loamy sand, 0 to 6 percent slopes	Slight	5200	A
Boyer loamy sand, 6 to 12 percent slopes	Moderate	5750	A,G
Boyer sandy loams, 0 to 6 percent slopes	Slight	5200	A
Boyer sandy loams, 6 to 12 percent slopes	Moderate	5750	A,G
Boyer-Spinks loamy sands, 12 to 18 percent slopes	Severe	5950	A,G
For Spinks part see Spinks series			
Brady-Bronson sandy loams, 0 to 3 percent slopes	Severe	6400	B,H
For Bronson part see Bronson series			
Bronson series	Severe	6400	B,H
Mapped only in a complex with Brady soils			
Capac loam, 0 to 3 percent slopes	Severe	6400	B,H
Capac-Marlette loams, 1 to 6 percent slopes	Severe	6400	B,H
For Marlette part see Marlette series			
Cohoctah fine sandy loam, frequently flooded	Severe	8750	C,F,H
Colwood loam	Severe	8750	C,F,H
Colwood loam, depressional	Severe	8750	C,F,H
Edwards muck	Severe	9700	C,D,F,H
Gilford sandy loam	Severe	8750	C,F,H
Hillsdale sandy loam, 2 to 6 percent slopes	Slight	5200	A

Table 4-10. Continued

Soil Map Unit	Soil Limitation	Initial Cost per Dwelling Site ($1978)	Corrective Measures
Hillsdale sandy loam, 6 to 12 percent slopes	Moderate	5750	A,G
Houghton muck	Severe	9700	C,D,F,H
Kibbie fine sandy loam, 0 to 3 percent slopes	Severe	6400	B,H
Lenawee silty clay loam, depressional	Severe	8750	C,F,H
Marlette loam, 2 to 6 percent slopes	Slight	5200	A
Marlette loam, 6 to 12 percent slopes	Moderate	5750	A,G
Marlette clay loam, 6 to 12 percent, severely eroded	Moderate	5750	A,G
Marlette loam, 12 to 18 percent slopes	Severe	5950	A,G
Marlette loam, 18 to 25 percent slopes	Severe	6200	A,G
Matherton loam, 0 to 3 percent slopes	Severe	6400	B,H
Metamora-Capac sandy loam, 0 to 4 percent slopes	Severe	6400	B,H
For Capac part see Capac series			
Metea			
Mapped only in complex with Spinks soils			
Metea part of Spinks-Metea loamy sands, 0 to 6 percent slopes	Moderate	5200	A
Metea part of Spinks-Metea loamy sands, 6 to 12 percent slopes	Moderate	5720	A,G
Oshtemo sandy loam, 0 to 6 percent slopes	Slight	5200	A
Oshtemo sandy loam, 6 to 12 percent slopes	Moderate	5750	A,G
Owosso-Marlette sandy loams, 1 to 6 percent slopes	Slight	5200	A
For Marlette part see Marlette series			

Table 4-10. Continued

Soil Map Unit	Soil Limitation	Initial Cost per Dwelling Site ($1978)	Corrective Measures
Owosso-Marlette sandy loams, 6 to 12 percent slopes	Moderate	5750	A,G
For Marlette part see Marlette series			
Owosso-Marlette sandy loams, 12 to 18 percent slopes	Severe	5950	A,G
For Marlette part see Marlette series			
Palms muck	Severe	9700	C,D,F,H
Parkhill loam	Severe	8750	C,F,H
Sebewa loam	Severe	8750	C,F,H
Shoals-Sloan loams	Severe	8750	C,F,H
For Sloan part see Sloan series			
Sloan Series	Severe	8750	C,F,H
Mapped only in complex with Shoals series			
Spinks loamy sand, 0 to 6 percent slopes	Slight	5200	A
Spinks-Metea loamy sands, 0 to 6 percent slopes	Slight	5200	A
For Metea part see Metea series			
Spinks loamy sand, 6 to 12 percent slopes	Moderate	5750	A,G
Spinks-Metea loamy sands, 6 to 12 percent slopes	Moderate	5750	A,G
For Metea part see Metea series			
Spinks part of Boyer-Spinks loamy sands, 12 to 18 percent slopes	Severe	5950	A,G
Tuscola fine sandy loam, 0 to 4 percent slopes	Severe	6400	B,H

Table 4-10. Continued

Soil Map Unit	Soil Limitation	Initial Cost per Dwelling Site ($1978)	Corrective Measures
Wasepi sandy loam, 0 to 3 percent slopes	Severe	6400	B,H
Wasepi sandy loam, bedrock variant, 0 to 3 percent slopes	Severe	7000	B,E
Winneshiek silt loam, 0 to 3 percent slopes	Moderate	7000	B,E

A = Conventional basement design
B = Alternative drained basement design
C = Alternative undrained basement design
D = Excavate peat and muck
E = Excavate rock
F = Raise grade of building site
G = Cuts and fills
H = Improve drainage control

listed in this table are generalized estimates in 1978 dollars of the costs required to grade a proposed building site on each soil, excavate and install a basement foundation, and provide drainage if the soil is wet. They are clearly not intended to eliminate the need for cost estimating by home builders and others on a site-by-site basis. The dollar amount listed for each soil is the mean of the range in costs (Appendix Table C3) for installing these different corrective measures. These were computed from cost analyses of completed residential building projects in the county, obtained from home builders, construction trade organizations, engineers, architects, and others.

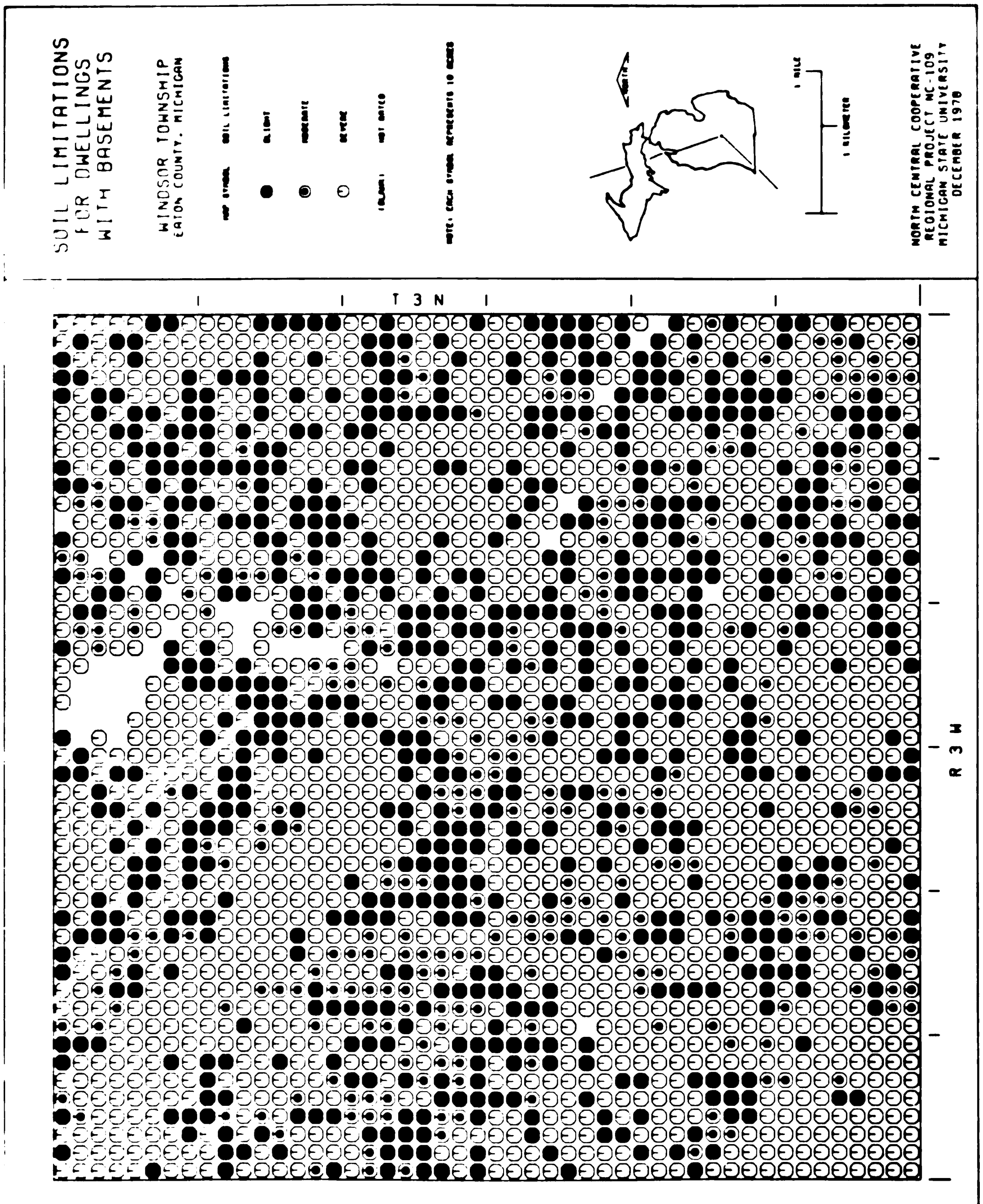
The average initial costs for installing the basements with the different corrective measures where needed, on the soils in Eaton County, Michigan ranges from \$5,200 to \$9,700 (Table 4-10) per dwelling site. These data clearly indicate the need for additional investment and alternative foundation designs (B and C designs) for soils with moderate to severe limitations. Soils with slight limitations (e.g., Bixby loam, Hillsdale sandy loam, 2 to 6 percent slopes, Oshtemo sandy loam, 0 to 6 percent slopes) require only an initial investment of about \$5,200 for installation of conventional basements (A), while those soils with moderate limitations (e.g., Hillsdale sandy loam, 6 to 12 percent slopes, Oshtemo sandy loam, 6 to 12 percent slopes, Owosso-Marlette sandy loams, 6 to 12 percent slopes) require an additional expenditure of about \$550, (\$5,750 total) primarily because of the increased site grading (G) required. Further study of the data reveals that the initial costs for soils with severe limitations (e.g., Boyer-Spinks loamy sands, 12 to 18 percent slopes, Kibbie fine sandy loam, 0 to 3 percent slopes, Palms muck) are higher ranging from \$5,950 to \$9,700. The organic soils mapped in this county (Adrian, Edwards, Houghton, and Palms) have the highest initial costs (\$9,700) for basements in home construction among all the soils listed in Table 4-10. In fact, their costs are 87 percent greater than the costs required to build dwellings with basements on soils having only slight limitations for this use. This clearly illustrates the reason why organic soils should be avoided for building residential dwellings with basements, if at all possible.

Computer Output

Figure 4-13 illustrates the locations of areas with soil limitations for residential dwellings with basements in Windsor Township, Eaton County, Michigan. The basic format of this computer-generated map is again essentially the same as those previously presented in this chapter. The darkest or black octagons represent areas which have only slight limitations for this use, while those areas with severe soil limitations are represented by unshaded or white octagons. Areas with moderate soil limitations are then represented by octagons which are intermediate in tone. Blank cells represent unrated borrow land and water areas.

A visual examination of this map reveals that much of the land in the township has severe limitations for residential

Figure 4-13.--Computer-drawn interpretive map illustrating soil limitations for residential dwellings with basements in Windsor Township.


SOIL LIMITATIONS
FOR DWELLINGS
WITH BASEMENTS
WINDSOR TOWNSHIP
EATON COUNTY, MICHIGAN
NORTH CENTRAL COOPERATIVE
REGIONAL PROJECT NC-109
MICHIGAN STATE UNIVERSITY
DECEMBER 1978
T 3 N
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dwellings with basements. The most predominant area again striddles the "Old Maid Swamp" (see Figure 1-3) in the northeast quadrant of the township. This area consists of nearly level, poorly and very poorly drained, mucky and loamy soils (i.e., Adrian, Colwood, Edwards, Gilford, Houghton, Palms, Parkhill, etc.) located in ancient glacial drainageways. This elongated area includes the swamp with muck soils and other low-lying soils with seasonal water tables near or at the soil surface. Another large area with similarly rated soils (i.e., Capac, Gilford, Houghton, Sebewa, etc.) is located in the extreme southwest corner of the township (Figure 4-13). Soils in these two areas present serious problems in the construction of residential dwellings with basements. However, the organic soils of the group (Adrian, Edwards, Houghton, and Palms) have considerably more difficult soil limitations to overcome (i.e., peat and muck at great depths) requiring additional corrective measures, thereby increasing the cost of residential construction.

The spatial distribution of soil areas with only slight or moderate limitations for residential dwellings with basements is also well illustrated in Figure 4-13. These areas are scattered throughout the entire map. The most predominant area, however, is located in the west-central portion of the township, adjacent to U.S. Highway 27 (Temporary Interstate 69) and in vicinity of West Windsor (see Figure 1-2). A study of the soils map, sheets 29 and 30, of the county soil survey, indicates that Bixby, Boyer, Hillsdale, Marlette, Spinks, and Owosso soils dominate this landscape. Generally, these soils are well or moderately well drained, sandy loams or loamy sands occupying nearly level to gently undulating portions of glacial moraines or outwash plains. Their relatively deep depth to seasonal water tables insures that dwellings built on these soils are unlikely to have wet basements. These soils also have fair to good bearing capacity and provide good foundation support (Feenstra, et al., 1978). Those with steeper slopes have moderate limitations because some land grading is required, although the undulating topography is a definite advantage from an aesthetic standpoint for homesites. Slopes in cuts and fills in these soils are stable and fairly easily vegetated.

Table 4-11 shows the proportionate extent and approximate acreage of soils in Windsor Township with different degrees of limitations for residential dwellings with basements and sanitary sewers. These calculations are based on the number of cells in each category (slight, moderate, severe, unrated) as plotted on Figure 4-13. According to the information presented on the right side in this table, 7,189, 2,604, and 12,832 acres have slight, moderate, and severe limitations for residential dwellings with basements, respectively. These data then indicate that 42.5 percent of the land (9,793 acres) in the township has slight or moderate limitations for residential dwellings with basements, and is therefore suitable for use without special foundation, designs or additional grading and drainage, while more than half

Table 4-11. Proportionate extent and approximate acreage of soils classified by soil limitations and potentials for residential dwellings with basements in Windsor Township, Eaton County, Michigan

Degree of Soil Limitation	Soil Potential Rating: Excellent		Good		Fair		Poor		Unrated		Total	
	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres
Slight	31.2	7187	-	-	-	-	-	-	-	-	31.2	7189
Moderate	11.3	2604	-	-	-	-	-	-	-	-	11.3	2604
Severe	1.6	368	30.4	7004	13.2	3041	10.5	2419	-	-	55.7	12833
Unrated	-	-	-	-	-	-	-	-	1.8	415	1.8	415
Total	44.1	10161	30.4	7004	13.2	3041	10.5	2419	1.8	415	100.0	23040

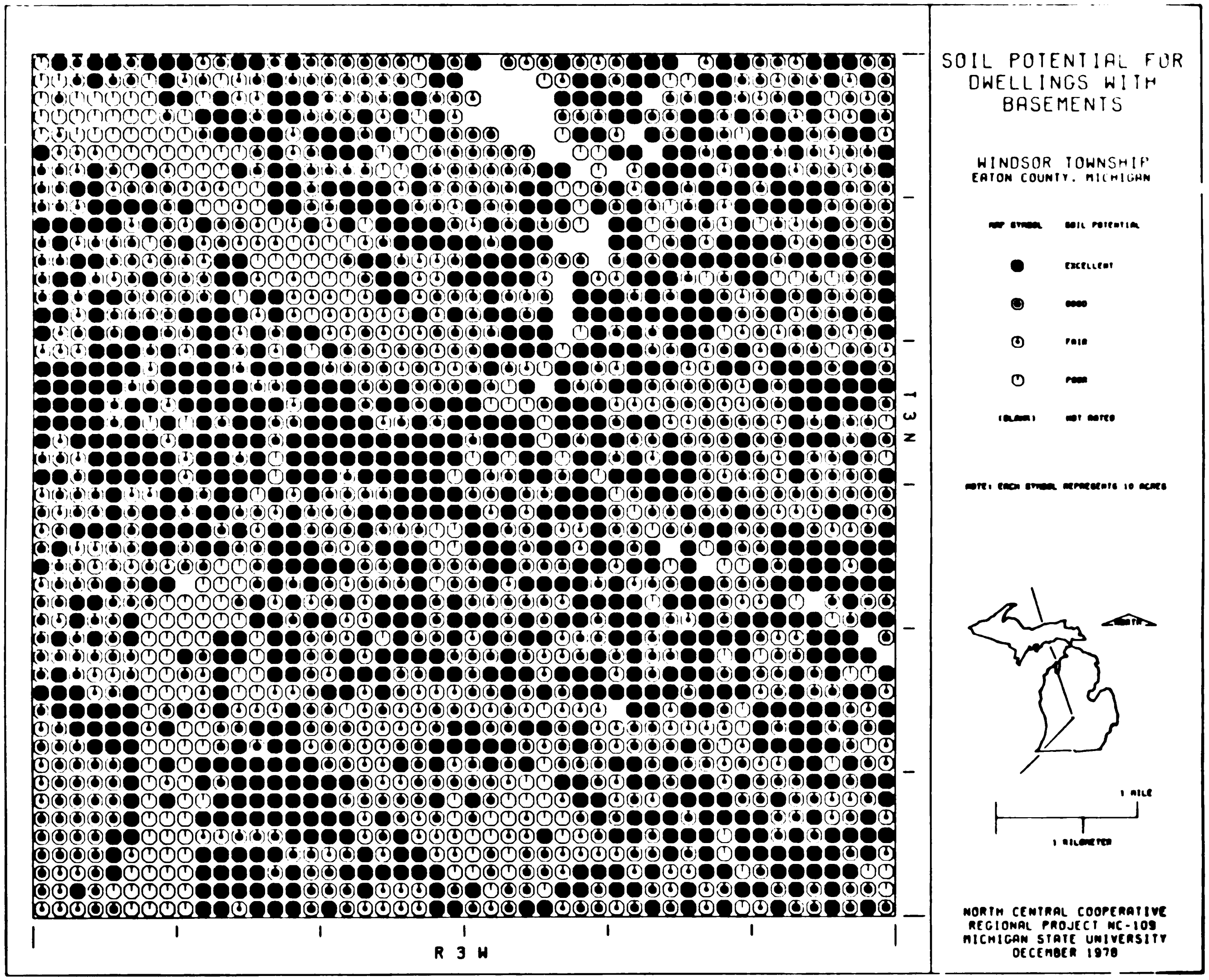
NOTE: Calculations are based on Figure 4-13 and 4-14 (2304 cells, 10 acres per cell) of the land area (55.7 percent or 12,832 acres) has severe soil limitations for these same land uses, usually requiring more costly alternative corrective measures.

Significant changes can occur, however, in the amount of suitable land this nonagricultural land use by applying different corrective measures on soils with moderate or severe limitations. Table 4-11 shows the proportionate extent and approximate acreage of soils in Windsor Township classified according to their potential for residential dwellings with basements and sanitary sewers. According to the information presented along the bottom of this table, 10,161, 7,004, 3,041, and 2,419 acres have excellent, good, fair, and poor potential for this land use. Further study of these data indicates that out of the 12,833 acres of land in the township, which are rated as having severe soil limitations, 81.2 percent of this land area has excellent, good, or fair potential for dwellings with basements. This is a significant increase of 106 percent or 10,413 acres in the amount of land that might be suitable for this land use in the township, provided that the proper corrective measures are applied to each soil where needed (Appendix Table F3). Even more significant is the fact that only 10.5 percent of the land area in the township has soils with poor potential, while 44.1 and 30.4 percent have soils with excellent and good potential, respectively. From these data it is obvious that Windsor Township has a quite favorable distribution of soils for this type of urban development.

Figure 4-14 shows the location of soils with different potentials for residential dwellings with basements and sanitary sewers in Windsor Township. It is evident that there are only a few predominant areas on the map which have high concentrations of soils with poor potential for this land use. One such area is located in the northwest quadrant of the township straddling the "Old Maid Swamp." Another elongated area is situated in the southwest quadrant of the township along the King and Carleton drains (Figure 1-3). Several other areas of minor acreage are located near the Grand River (Figure 1-3). These areas essentially consist of very poorly drained organic soils or alluvial soils (Cohoctah, Sloan) requiring elaborate and costly corrective measures for residential dwellings with basements (Appendix Table F3 and Table 4-10). Although corrective measures can be applied to overcome some of their soil limitations, these soils are subject to flooding, and consequently, are among the poorest choices for building sites in the township.

Figure 4-14 shows that much of Windsor Township has soils with excellent, good, or fair potential for residential dwellings with basements and sanitary sewers. By visually comparing Figure 4-14 with the generalized land use and cover map for the same area (see Figure 4-9), it is clear that a degree of incompatibility and potential land use conflict exists. This overlap is most prevalent in the westcentral and southwest portions of the township where large contiguous soils areas have excellent and good

Figure 4-14.--Computer-drawn interpretive map illustrating soil potential for residential dwellings with basements in Windsor Township.



SOIL POTENTIAL FOR DWELLINGS WITH BASEMENTS
WINDSOR TOWNSHIP
EATON COUNTY, MICHIGAN
MAP SYMBOL
SOIL POTENTIAL
EXCELLENT
GOOD
FAIR
POOR
(BLANK)
NOT RATED
NOTE: EACH SYMBOL REPRESENTS 10 ACRES
NORTH
1 MILE
1 KILOMETER
NORTH CENTRAL COOPERATIVE
REGIONAL PROJECT NC-109
MICHIGAN STATE UNIVERSITY
DECEMBER 1978
T 3 N
R 3 W

potential for dwellings with basements. The implications of these potential land use conflicts are serious. Residential development of these suitable areas would destroy their high value for agriculture and forestry. This calls for priorities to be established carefully for the preservation of good land for food and fiber production, as well as providing land for urban development.

Residential Dwellings With Sanitary Sewers Without Basements

The soil potential index (SPI) and potential rating of each mapping unit for residential dwellings without basements in Eaton County, Michigan, is shown in Table 4-12. The SPI ranges from a high of 100 for Boyer loamy sand, 0 to 6 percent slopes, to a low of 1 for Palms muck. As shown in this table, all map units were also arrayed from excellent to poor potential according to their soil potential index. The class intervals generated by a JENKS computer program (see Table 3-8), with the maximum goodness of variance fit (98.11%), were used to assign each mapping unit to one of the four qualitative rating classes indicating its relative potential for residential dwellings without basements in the county. Note that the areas mapped as water and borrow land were again left unrated for the reasons previously discussed.

Corrective Measures and Continuing Limitations

In cooperation with private home builders and home construction trade organizations, as well as local engineers and architects, designs for residential dwellings without basements

Table 4-12. Soil potential index and rating of soil mapping units for residential dwellings without basements in Eaton County, Michigan

Soil Potential Index	Soil Potential Rating	Soil Map Unit
100	Excellent	Boyer loamy sand, 0 to 6 percent slopes
100	Excellent	Boyer sandy loams, 0 to 6 percent slopes
100	Excellent	Hillsdale sandy loam, 2 to 6 percent slopes
100	Excellent	Oshtemo sandy loam, 0 to 6 percent slopes
100	Excellent	Spinks loamy sand, 0 to 6 percent slopes
93	Excellent	Spinks-Metea loamy sands, 6 to 12 percent slopes
82	Good	Bixby loam, 0 to 3 percent slopes
82	Good	Boyer loamy sands, 6 to 12 percent slopes
82	Good	Boyer sandy loams, 6 to 12 percent slopes
82	Good	Hillsdale sandy loam, 6 to 12 percent slopes
82	Good	Marlette loam, 2 to 6 percent slopes
82	Good	Oshtemo sandy loam, 6 to 12 percent slopes
82	Good	Owosso-Marlette sandy loams, 1 to 6 percent slopes
82	Good	Spinks loamy sand, 6 to 12 percent slopes

Table 4-12. Continued

Soil Potential Index	Soil Potential Rating	Soil Map Unit
82	Good	Spinks-Metea loamy sands, 6 to 12 percent slopes
82	Good	Tuscola fine sandy loam, 0 to 4 percent slopes
82	Good	Winneshiek silt loam, 0 to 3 percent slopes
71	Good	Marlette loam, 6 to 12 percent slopes
71	Good	Marlette clay loam, 6 to 12 percent slopes, severely eroded
71	Good	Owosso-Marlette sandy loams, 6 to 12 percent slopes
70	Good	Brady-Bronson sandy loams, 0 to 3 percent slopes
70	Good	Capac-Marlette loams, 1 to 6 percent slopes
64	Fair	Capac loam, 0 to 3 percent slopes
64	Fair	Kibbie fine sandy loam, 0 to 3 percent slopes
64	Fair	Matherton loam, 0 to 3 percent slopes
64	Fair	Metamora-Capac sandy loams, 0 to 4 percent slopes
64	Fair	Wasepi sandy loam, 0 to 3 percent slopes
64	Fair	Wasepi sandy loam, bedrock variant, 0 to 3 percent slopes
55	Fair	Boyer-Spinks loamy sands, 12 to 18 percent slopes

Table 4-12. Continued

Soil Potential Index	Soil Potential Rating	Soil Map Unit
55	Fair	Colwood loam
55	Fair	Colwood loam, depressional
55	Fair	Gilford sandy loam
55	Fair	Lenawee silty clay loam, depressional
55	Fair	Marlette loams, 12 to 18 percent slopes
55	Fair	Owosso-Marlette sandy loams, 12 to 18 percent slopes
55	Fair	Parkhill loam
55	Fair	Sebewa loam
43	Poor	Cohoctah fine sandy loam, frequently flooded
43	Poor	Marlette loam, 18 to 25 percent slopes
43	Poor	Shoals-Sloan loam
1	Poor	Adrian muck
1	Poor	Edwards muck
1	Poor	Houghton muck
1	Poor	Palms muck
-	Unrated	Borrow land
-	Unrated	Water

but with sanitary sewers were identified for soils in Eaton County, Michigan. Appendix Table F4 lists the features affecting the use, recommended designs to overcome these limitations, and a statement of the kinds of limitations remaining after these foundations designs are installed on these soils. As shown in this table, there are six kinds of corrective measures commonly used, either separately or concurrently, on soils in the county to overcome problem soil conditions. These are the following: reinforce slab, add fill to raise grade of site, excavate peat and muck, cutting and filling, drainage of footing and slab, and improve surface drainage. A brief description of each is presented below.

(1) Reinforce slab.

Slabs-on-grade are concrete foundation slabs which rest directly on a prepared base course underlain by either undisturbed soil or compacted fill (Figure 4-15). These have been used extensively in residential construction since the large home-building expansion after World War II because of their low cost and, generally speaking, simple construction (Federal Insurance Administration, HUD, 1977).

In a 1968 report for the Federal Housing Administration, the Building Research Advisory Board of the National Academy of Sciences recognized four different basic slab types (Building Research Advisory Board, FHA, 1968):

Type I: Unreinforced
Type II: Lightly reinforced against shrinkage and temperature cracking

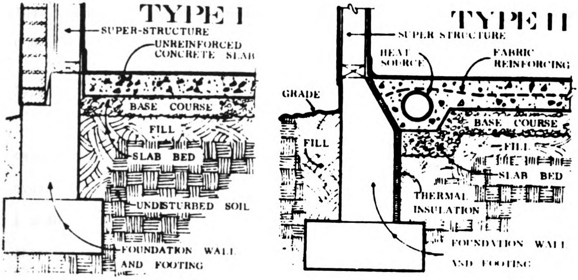


Figure 4-15.--Cross-section of Type I and II slabs-on-grade.

SOURCE: Building Research Advisory Board, FHA, 1968.

Type III: Reinforced and stiffened
Type IV: Structural (not directly supported on the ground).

The first three are ground supported slabs, while the last is structurally supported independent of the ground, resting on piers, piles, or grade beams. The advisory board concluded in their report that in most cases a slab of Type I or II, as illustrated in Figure 4-15, would be completely satisfactory. They indicated that the choice between an unreinforced slab and a lightly reinforced one is primarily then influenced by subsoil conditions.

Type I slab

This is defined as a concrete slab at least 4-inch thick cast directly on a compacted slab bed and carrying no reinforcement over its entire area (Figure 4-15). Being unreinforced, the Type I slab lacks the necessary strength to withstand significant changes in volume of the slab bed. Its use therefore is limited to areas with firm ground which will not develop changes in volume with time. Type I slabs then should be placed only on well-drained and properly graded coarse-grained soils not subject to volume changes. Note from Figure 4-15 that the superstructure loads are supported independently on the slab on foundation walls and footings.

Type II slabs

Type II slabs are lightly reinforced over their entire length (Figure 4-15) and are applicable to building sites where soils may undergo differential movements due to expansion and contraction. The welded-wire fabric reinforcement throughout their 4 inch thickness enables the slab to accommodate throughout these small changes and helps to control the size of shrinkage cracking. Since the slab can now accommodate thermal stresses, heating sources, such as pipes, ducts, or coils, can also be embedded in the slab.

(2) Add fill to raise grade of site.

Where slab-on-ground construction is intended, there is commonly a need for some preparation of the subgrade. Fills are used by home builders to raise the existing grade of the building sites located in depressions or low-lying areas above base flood levels or high ground water tables. Once soil materials are compacted to a suitable density, they can provide foundation support for Type I and Type II slabs on grade. Again, as previously mentioned, it is not the intent of this investigator to suggest that dwellings without basements should be built on floodprone or wetland areas, but rather where such construction may be appropriate, and not prohibited by law or regulation, flood losses to those dwellings constructed above base flood levels can be minimized. Although property losses may be minimized by use of this construction practice, property accessibility can still be restricted and yard use all but eliminated during periods of prolonged flooding.

(3) Excavate of peat and muck.

Peat and muck soils make unsuitable subgrade materials for dwellings without basements since they are highly compressible and have low bearing strength (Tilmann and Mokma, 1976). Type I and II ground-supported slabs require that their slab bed not expand or contact due to changes in moisture. Where dwellings with slabs on grade are constructed on sites consisting of these soils, the common practice is to excavate down to their mineral horizons and replace these materials with suitable compacted borrow. This will provide firm support for the foundation slab.

(4) Cutting and filling.

Land grading is used in residential development in undulating or hilly topography to create reasonably level areas for slab-on-ground construction. As slope gradient increases, however, the volume of material that must be moved in order to level the dwelling site increases geometrically, as does construction costs and soil and water control problems (Urban Land Institute, 1978). Since all grading causes erosion to a certain degree, steeply sloping sites and critically erodible soils should, therefore, be left undisturbed or disturbed areas kept as small as possible to minimize soil losses. Those that are disturbed should be treated with adequate soil erosion control measures, as soon as possible, to retain sediment onsite. Maintenance costs can obviously be greater for these practices as slope gradient increases.

(5) Drainage of footing and slab.

High ground water tables can pose serious problems for dwellings with slabs-on-grade. If moisture can migrate through the slab, then flooring materials and heating ducts could be extensively ruined. This subsurface water is usually collected by drain tile placed around and under the slab. The collected water then drains by gravity to an outlet at a lower elevation. This subdrainage system is effective in minimizing the general wetting of the foundation soils due to the migration of free soil water.

(6) Improve drainage.

The subsurface drainage system used to collect and dispose of free soil water from dwelling sites with slabs on grade is the same as that used to drain dwelling sites with basements.

Cost of Corrective Measures

Table 4-13 presents the estimated costs of applying different corrective measures to overcome soil limitations for residential dwellings without basements in Eaton County, Michigan. The figures listed in this table are generalized estimates in 1978 dollars of the costs required to grade a proposed building site on each soil, excavate and install a slab on grade and provide drainage if the soil is wet. They are clearly not intended to eliminate the need for cost estimating by home builders and others on a site-by-site basis. The dollar amount listed for each soil is the mean of the range of costs (Appendix Table C4) for installing these different corrective measures. They were computed from cost analyses of completed residential building projects in the county, obtained

Table 4-13. Soil limitations and estimated costs of applying different corrective measures for residential dwellings without basements in Eaton County, Michigan

Soil Map Unit	Soil Limitation	Initial Cost per Dwelling Site ($1978)	Corrective Measure
Adrian muck	Severe	5400	B,C,D,G
Bixby loam, 0 to 3 percent slopes	Moderate	3750	B
Borrowland	Properties to variable to be rated		
Boyer loamy sand, 0 to 6 percent slopes	Moderate	3250	A
Boyer loamy sand, 6 to 12 percent slopes	Moderate	3750	A,E
Boyer sandy loams, 0 to 6 percent slopes	Moderate	3250	A
Boyer sandy loams, 6 to 12 percent slopes	Moderate	3750	A,E
Boyer-Spinks loamy sands, 12 to 18 percent slopes	Severe	4000	A,E
For Spinks part see Spinks series			
Brady-Bronson sandy loams, 0 to 3 percent slopes	Severe	4300	B,F,G
For Bronson part see Bronson series			
Bronson series	Severe	3750	B
Mapped only in a complex with Brady soils			
Capac loam, 0 to 3 percent slopes	Severe	4300	B,F,G
Capac-Marlette loams, 1 to 6 percent slopes	Severe	4300	B,F,G
For Marlette part see Marlette series			
Cohoctah fine sandy loam, frequently flooded	Severe	4750	B,C,F,G
Colwood loam	Severe	4750	B,C,F,G
Colwood loam, depressional	Severe	4750	B,C,F,G
Edwards muck	Severe	5400	B,C,D,G
Gilford sandy loam	Severe	4750	B,C,F,G

Table 4-13. Continued

Soil Map Unit	Soil Limitation	Initial Cost per Dwelling Site ($1978)	Corrective Measure
Hillsdale sandy loam, 2 to 6 percent slopes	Moderate	3250	A
Hillsdale sandy loam, 6 to 12 percent slopes	Moderate	3750	B,E
Houghton muck	Severe	5400	B,C,D,G
Kibbie fine sandy loam, 0 to 3 percent slopes	Severe	4300	B,F,G
Lenawee silty clay loam, depressional	Severe	4750	B,C,G
Marlette loam, 2 to 6 percent slopes	Moderate	3750	B
Marlette loam, 6 to 12 percent slopes	Moderate	4200	B,E
Marlette clay loam, 6 to 12 percent, severely eroded	Moderate	4200	B,E
Marlette loam, 12 to 18 percent slopes	Severe	45000	B,E
Marlette loam, 18 to 25 percent slopes	Severe	4750	B,E
Matherton loam, 0 to 3 percent slopes	Severe	4300	B,F,G
Metamora - Capac sandy loam, 0 to 4 percent slopes	Severe	4300	B,F,G
For Capac part see Capac series			
Metea			
Mapped only in complex with Spinks soils			
Metea part of Spinks-Metea loamy sands, 0 to 6 percent slopes	Moderate	3750	B
Metea part of Spinks-Metea loamy sands, 6 to 12 percent slopes	Moderate	4250	B,E
Oshtemo sandy loam, 0 to 6 percent slopes	Slight	3250	A
Oshtemo sandy loam, 6 to 12 percent slopes	Moderate	3750	A,E

Table 4-13. Continued

Soil Map Unit	Soil Limitation	Initial Cost per Dwelling Site ($1978)	Corrective Measure
Owosso-Marlette sandy loams, 1 to 6 percent slopes	Moderate	3750	B,E
For Marlette part see Marlette series			
Owosso Marlette sandy loams, 6 to 12 percent slopes	Moderate	4250	B,E
For Marlette part see Marlette series			
Owosso-Marlette sandy loams, 12 to 18 percent slopes	Severe	4500	B,E
For Marlette part see Marlette series			
Palms muck	Severe	5400	B,C,D,G
Parkhill loam	Severe	4750	B,C,F,G
Sebewa loam	Severe	4750	B,C,F,G
Shoals-Sloan loams	Severe	4750	B,C,F,G
For Sloan part see Sloan series			
Sloan Series	Severe	4750	B,C,F,G
Mapped only in complex with Shoals series			
Spinks loamy sand, 0 to 6 percent slopes	Slight	3250	A
Spinks-Metea loamy sands, 0 to 6 percent slopes	Slight	3250	A
For Metea part see Metea series			
Spinks loamy sand, 6 to 12 percent slopes	Moderate	3750	A,E
Spinks-Metea loamy sands, 6 to 12 percent slopes	Moderate	3750	A,E
For Metea part see Metea series			
Spinks part of Boyer-Spinks loamy sands, 12 to 18 percent slopes	Severe	4000	A,E

Table 4-13. Continued

Soil Map Unit	Soil Limitation	Initial Cost per Dwelling Site ($1978)	Corrective Measure
Tuscola fine sandy loam, 0 to 4 percent slopes	Severe	3750	B
Wasepi sandy loam, 0 to 3 percent slopes	Severe	4300	B,F,G
Wasepi sandy loam, bedrock variant, 0 to 3 percent slopes	Severe	4300	B,F,G
Winneshiek silt loam, 0 to 3 percent slopes	Moderate	3750	B

A = Type I slab on grade
B = Type II slab on grade
C = Add fill to raise grade
D = Excavate muck
E = Cuts and fills
F = Drainage of footing and slab
G = Improve drainage control

from home builders, construction trade organizations, engineers, architects, and others.

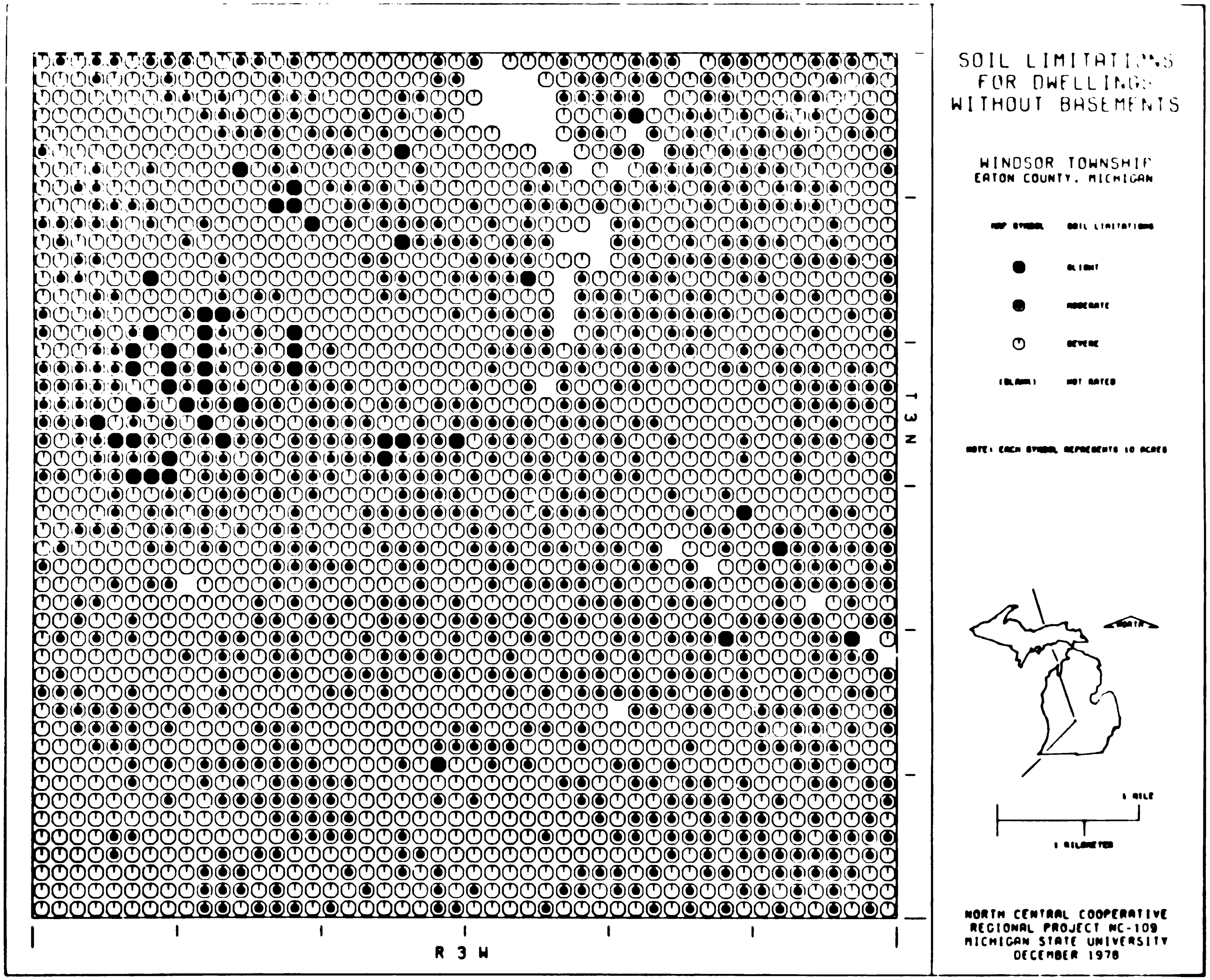
The average initial costs for installing the different corrective measures on these soils in Eaton County, Michigan, ranges from \$3,250 to \$5,400 (Table 4-13) per dwelling site. These data clearly indicate the need for additional investment and reinforced foundation designs (Type II slab) for soils with moderate to severe limitations (e.g., Capac loam, 0 to 3 percent slopes, Marlette loam, 6 to 12 percent slopes, Tuscola fine sandy loam, 0 to 4 percent slopes). Soils with slight limitations (e.g., Oshtemo sandy loam, 0 to 6 percent slopes, Spinks loamy sand, 0 to 6 percent slopes) require only an initial investment of about \$3,250 for installation of Type I slabs on grade (A), while similar soils with moderate limitations because of slope (e.g., Oshtemo sandy loam, 6 to 12 percent slopes, Spinks loamy sand, 6 to 12 percent slopes) require an additional expenditure on the average of about \$500 (\$3,750 total), primarily because of the increased site grading (G) required. Further study of the data reveals that the initial costs for organic soils with severe limitations (e.g., Adrian, Edwards, Houghton, and Palms) have the highest costs for home construction without basements among all the soil listed in Table 4-13. In fact, their costs are 66 percent greater than those required to build similar dwellings on soils having only slight limitations for this use. This again clearly illustrates the reason why organic soils should be avoided for home construction, if at all possible.

Computer Output

Figure 4-16 illustrates the locations of areas with soil limitations for residential dwellings without basements in Windsor Township, Eaton County, Michigan. The basic format of this computer-generated map is again essentially the same as those previously presented in this chapter. The darkest or black octagons represent areas which have only slight limitations for this use, while those areas with severe soil limitations are represented by unshaded or white octagons. Areas with moderate soil limitations are thus represented by octagons which are intermediate in tone. Blank cells represent unrated borrow land and water areas.

A visual examination of this map reveals that much of the land in the township has severe limitations for this land use. The most prominent area again straddles the "Old Maid Swamp" (Figure 1-3) in the northeast quadrant of the township. This elongated area consists, as previously discussed, of nearly level, poorly and very poorly drained mucky and loamy soils (i.e., Adrian, Colwood, Edwards, Gilford, Houghton, Palms, Parkhill, etc.) located in ancient glacial drainageways. Another large area with similarly rated soils (i.e., Capac, Gilford, Houghton, Sebewa, etc.) is located in an extreme southwest corner of the township (Figure 4-15). Soils in these two areas present serious problems for the construction of dwellings without basements, although the organic soils of the group (Adrian, Edwards, Houghton, and Palms) have again considerably more difficult soil limitations to overcome

Figure 4-16.--Computer-drawn interpretive map illustrating soil limitations for residential dwellings without basements in Windsor Township.


SOIL LIMITATIONS
FOR DWELLINGS
WITHOUT BASEMENTS
WINDSOR TOWNSHIP
EATON COUNTY, MICHIGAN
MAP SYMBOL
SOIL LIMITATIONS
SLIGHT
MODERATE
SEVERE
(BLANK)
NOT RATED
NOTE: EACH SYMBOL REPRESENTS 10 ACRES
NORTH
1 MILE
1 KILOMETER
NORTH CENTRAL COOPERATIVE
REGIONAL PROJECT NC-109
MICHIGAN STATE UNIVERSITY
DECEMBER 1978
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(i.e., peat and muck at great depths) requiring additional corrective measures (Appendix Table F4), thereby increasing the cost of residential construction.

The spatial distribution of soil areas with only slight or moderate limitations for residential dwellings without basements is also well illustrated in Figure 4-16. These areas are generally scattered throughout the entire map. Again, the most prominent area is located in the west-central portion of the township, adjacent to U.S. Highway 27 (Temporary Interstate 69) and in the vicinity of West Windsor (see Figure 1-2). A study of the soils map, sheets 29 and 30, of the county soil survey, indicates that Bixby, Boyer, Hillsdale, Marlette, Spinks, and Owosso soils dominate this landscape. These well or moderately drained soils have deep depths to seasonal water tables insuring that foundation slabs built on these soils are unlikely to be wet. Their bearing capacity is fair to good and they provide good foundation support for slabs on grade. Those with steeper slopes have moderate limitations because some land grading is required, although the undulating topography is a definite advantage from an aesthetic standpoint for homesites. Slopes in cuts and fills in these soils are quite stable and fairly easily vegetated.

Table 4-14 shows the proportionate extent and approximate acreage of soils in Windsor Township with different degrees of limitations for residential dwellings with sanitary sewers and without basements. These calculations are based on the number of

Table 4-14. Proportionate extent and approximate acreage of soils classified by soil limitations and potentials for residential dwellings without basements in Windsor Township, Eaton County, Michigan

Degree of Soil Limitation	Soil Potential Rating											
	Excellent		Good		Fair		Poor		Unrated		Total	
	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres
Slight	2.0	461	-	-	-	-	-	-	-	-	2.0	461
Moderate	2.2	507	38.3	8824	-	-	-	-	-	-	40.5	9331
Severe	-	-	2.9	668	42.1	9700	10.7	2465	-	-	55.7	12833
Unrated	-	-	-	-	-	-	-	-	1.8	415	1.8	415
Total	4.2	968	41.2	9492	42.1	9700	10.7	2465	1.8	418	100.0	23040

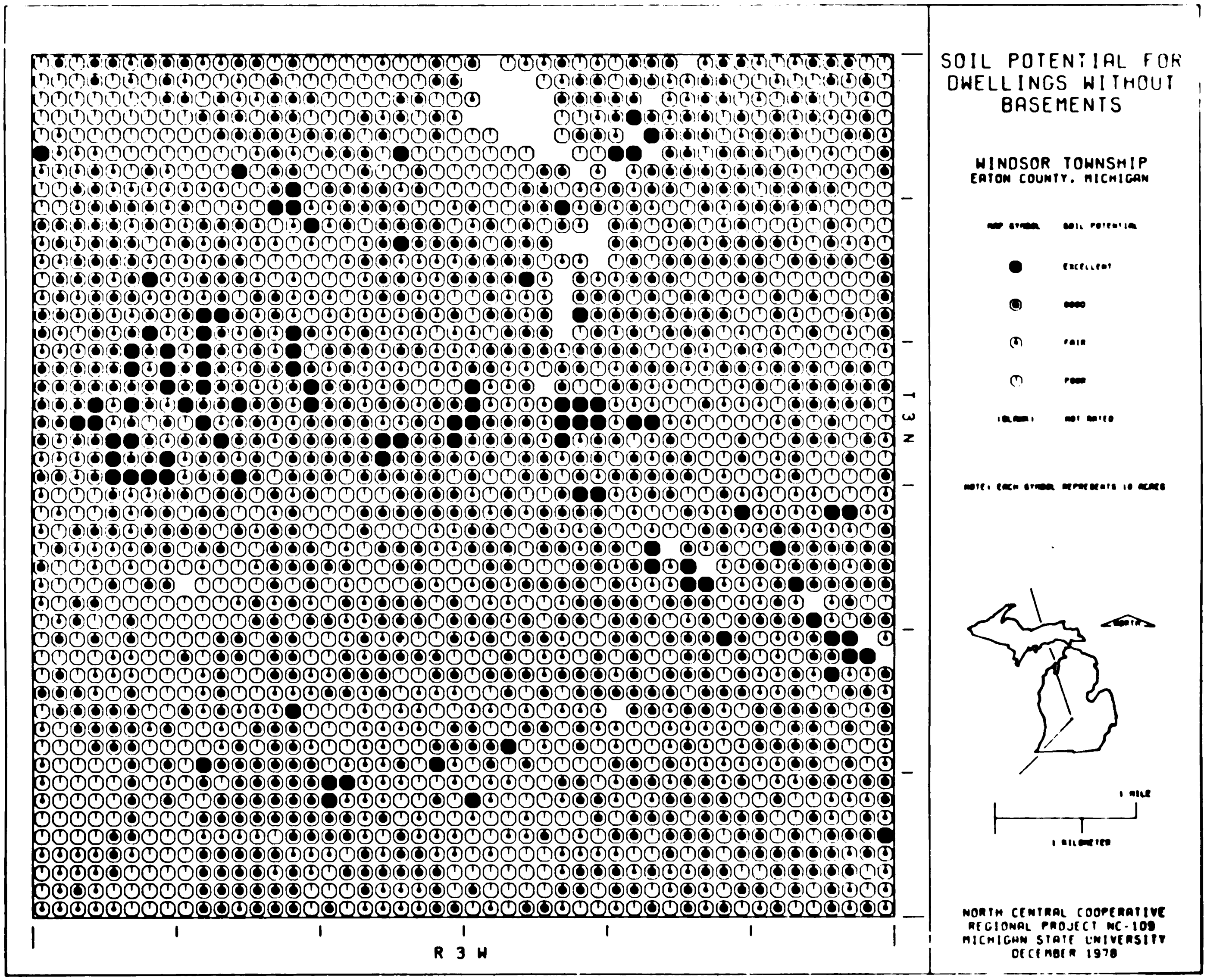
NOTE: Calculations are based on Figures 4-16 and 4-17 (2304 cells, 10 acres per cell) cells in each category (slight, moderate, severe, unrated) as plotted on Figure 4-16. According to the information presented on the right side of this table, 461, 9,331, and 12,833 acres have slight, moderate, and severe limitations for residential dwellings without basements, respectively. These data then indicate that about 42.5 percent of the land (9,792 acres) in the township has slight or moderate limitations for this land use, and is therefore suitable for use without special drainage systems for the slab bed or yard, while more than half of the land area (55.7 percent or 12,832 acres) has severe soil limitations for these same land uses, usually requiring more costly corrective measures for drainage or soil slope.

Significant changes can occur, however, in the amount of suitable land for this nonagricultural land use by applying different corrective measures on soils with moderate or severe limitations. Table 4-14 also shows the proportionate extent and approximate acreage of soils in Windsor Township classified according to this potential for residential dwellings without basements. According to the information presented along the bottom of this table, 968, 9,492, 9,700, and 2,465 acres have excellent, good, fair, poor potential, respectively, for this land use. A study of these data indicates that out of the 12,833 acres of land in the township which are rated as having severe soil limitations, 80.8 percent of this land area has good or fair potential for dwellings with sanitary sewers and without basements. This is a significant increase of 111 percent or 10,368 acres in the amount of land that might be suitable for this land use in the township, provided that the proper corrective measures are applied to each soil (Appendix Table F4). Even more significant is the fact that only 10.7 percent of the land area in the township has soils with poor potential, while 4.2 and 41.2 percent have soils with excellent and good potential, respectively.

Figure 4-17 shows the location of soils with different potentials for residential dwellings without basements in Windsor Township. It is evident that there are only a few prominent areas on the map which have high concentrations of soils with poor potential for this land use. One such area is located in the northwest quadrant of the township straddling the "Old Maid Swamp." Another elongated area is situated in the southwest quadrant of the township along the King and Carleton drains (Figure 1-3). Several other areas of minor acreage are located near the Grand River (Figure 1-3). These areas essentially consist of very poorly drained organic soils or alluvial soils (Cohoctah, Sloan) requiring elaborate and costly drainage control measures (Appendix Table F4 and Table 4-13). Although corrective measures can be applied to overcome some of their limitations, these soils are subject to flooding, and consequently are among the poorest choices for building sites in the township.

Figure 4-17 shows then that much of Windsor Township has soils with excellent, good, or fair potential for residential

Figure 4-17.--Computer-drawn interpretive map illustrating soil potential for residential dwellings without basements in Windsor Township.


SOIL POTENTIAL FOR
DWELLINGS WITHOUT
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WINDSOR TOWNSHIP
EATON COUNTY, MICHIGAN
MAP SYMBOL
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dwellings with sanitary sewers and without basements. By visually comparing Figure 4-16 with the generalized land use and cover map for the same area (see Figure 4-9), it is clear that a degree of incompatability and potential land use conflict exists. This overlap is most prevalent in the west-central and southwest portions of the township where large blocks of contiguous soil areas have excellent and good potential for dwellings without basements. Residential development of these suitable areas would likely destroy their high value for agriculture and forestry unless careful planning of priorities are established for the preservation of good land for food and fiber production, as well as providing land for urban development.

Residential Waterlines

The soil potential index (SPI) and potential rating of each mapping unit for residential waterlines in Eaton County, Michigan, is shown in Table 4-15. The SPI ranges from a high of 100 for Bixby loam, 0 to 3 percent slopes, to a low of 1 for Wasepi sandy loam, bedrock variant, percent slopes. As shown in this table, all map units were also arrayed from excellent to poor potential according to their soil potential index. The class intervals generated by the JENKS computer program (see Table 3-8), with the maximum goodness of variance fit (95.06%), were used to assign each mapping unit to one of the four qualitative rating classes indicating its relative potential for residential waterlines in the county. Note that the

Table 4-15. Soil potential index and rating of soil mapping units for residential waterlines in Eaton County, Michigan

Soil Potential Index	Rating	Soil Map Unit
100	Excellent	Bixby loam, 0 to 3 percent slopes
100	Excellent	Boyer loamy sand, 0 to 6 percent slopes
100	Excellent	Boyer sandy loams, 0 to 6 percent slopes
100	Excellent	Hillsdale sandy loam, 2 to 6 percent slopes
100	Excellent	Marlette loam, 2 to 6 percent slopes
100	Excellent	Oshtemo sandy loam, 0 to 6 percent slopes
100	Excellent	Owosso-Marlette sandy loams, 1 to 6 percent slopes
100	Excellent	Spinks loamy sand, 0 to 6 percent slopes
100	Excellent	Spinks-Metea loamy sands, 0 to 6 percent slopes
78	Good	Tuscola fine sandy loam, 0 to 4 percent slopes
78	Good	Wasepi sandy loam, 0 to 3 percent slopes
78	Good	Winneshiek silt loam, 0 to 3 percent slopes
70	Good	Capac-Marlette loams, 1 to 6 percent slopes
64	Good	Boyer loamy sands, 6 to 12 percent slopes
64	Good	Boyer sandy loams, 6 to 12 percent slopes

Table 4-15. Continued

Soil Potential Index	Rating	Soil Map Unit
64	Good	Hillsdale sandy loam, 6 to 12 percent slopes
64	Good	Marlette loam, 6 to 12 percent slopes
64	Good	Marlette loam, 6 to 12 percent slopes, severely eroded
64	Good	Oshtemo sandy loam, 6 to 12 percent slopes
64	Good	Owosso-Marlette sandy loams, 6 to 12 percent slopes
64	Good	Spinks loamy sand, 6 to 12 percent slopes
64	Good	Spinks-Metea loamy sands, 6 to 12 percent slopes
64	Good	Brady-Bronson sandy loams, 0 to 3 percent slopes
50	Fair	Capac loam, 0 to 3 percent slopes
50	Fair	Kibbie fine sandy loam 0 to 3 percent slopes
50	Fair	Matherton loam, 0 to 3 percent slopes
50	Fair	Metamora-Capac sandy loams, 0 to 4 percent slopes
45	Fair	Colwood loam
45	Fair	Colwood loam, depressional
45	Fair	Gilford sandy loam
45	Fair	Lenawee silty clay loam, depressional
45	Fair	Parkhill loam
45	Fair	Sebewa loam

Table 4-15. Continued

Soil Potential Index	Rating	Soil Map Unit
42	Poor	Cohoctah fine sandy loam, frequently flooded
42	Poor	Shoals-Sloan loams
40	Poor	Marlette loam, 12 to 28 percent slopes
40	Poor	Owosso-Marlette sandy loams, 12 to 18 percent slopes
27	Poor	Boyer-Spinks loamy sands, 12 to 18 percent slopes
24	Poor	Marlette loam, 18 to 25 percent slopes
21	Poor	Adrian muck
21	Poor	Edwards muck
21	Poor	Houghton muck
21	Poor	Palms muck
1	Poor	Wasepi sandy loam, bedrock variant, 0 to 3 percent slopes
-	Unrated	Borrow land
-	Unrated	Water

areas mapped as water and borrow land were again left unrated, as previously discussed.

Corrective Measures and Continuing Limitations

In cooperation with public works departments, professional trade organizations, and local engineers, designs for residential waterlines were identified for soils in Eaton County, Michigan. Appendix Table F4 lists the features affecting the use, recommended designs to overcome these limitations, and a statement of the kinds of limitations remaining after these waterline designs are installed on these soils. As shown in this table, there are seven kinds of corrective measures commonly used, either separately or concurrently, on soils in the county to overcome problem soil conditions. These are the following: install water pipe with pipe trencher, excavate peat and muck, excavate rock, dewater trench, wrap pipe with polyethylene, tamp backfill by hand, and thrust blocking and anchoring. A brief discussion of each is presented below.

(1) Install water pipe with pipe trencher.

Cast iron pipe has been commonly used for residential water lines where potable water is carried under pressure. Although in recent years thermoplastic pipe has been marketed as a low-cost substitute, cast iron pipe is still the preferred material among many public works agencies for waterlines because of its durability and resistence to high internal and external pressures.

In northern states, the usual procedure is to install the pipe in trenches below the maximum recorded depth of frost for the area (Cast Iron Pipe Research Association, 1951). The width of the trench must be sufficient to enable workmen to tamp the backfill around the bottom half of the pipe. A common rule of thumb, is that the trench should be from one to two feet wider than the outside of the pipe (Figure 4-18). Special trenching machines are used by some contractors to reduce or eliminate the need for sheeting or bracing the trench when installing small diameter (6 or 8 inches) pipes, thereby reducing costs of pipe laying.[21] Generally speaking, these trenches are not opened up very far ahead of pipe laying in order to reduce the possibility of cave-ins or flooding caused by ground water.

(2) Excavate peat and muck.

All water pipes should be placed on a stable foundation. Installing pipe on unstable peat and muck soils can result in uneven support and possible breakage under the weight of the backfill or above ground movements. A common practice is to excavate below the grade line and refill with material such as sand or gravel, thoroughly tamped, to bed the pipe. The pipe is then placed on this sand cushion (Figure 4-18).

(3) Excavate rock.

Where rock is encountered in trench excavation, it is also necessary that it be removed and a bed of sand be placed on the

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[21] Personal communication with W. Harry Smith, President, Cast Iron Pipe Research Association, Oak Brook, Illinois.

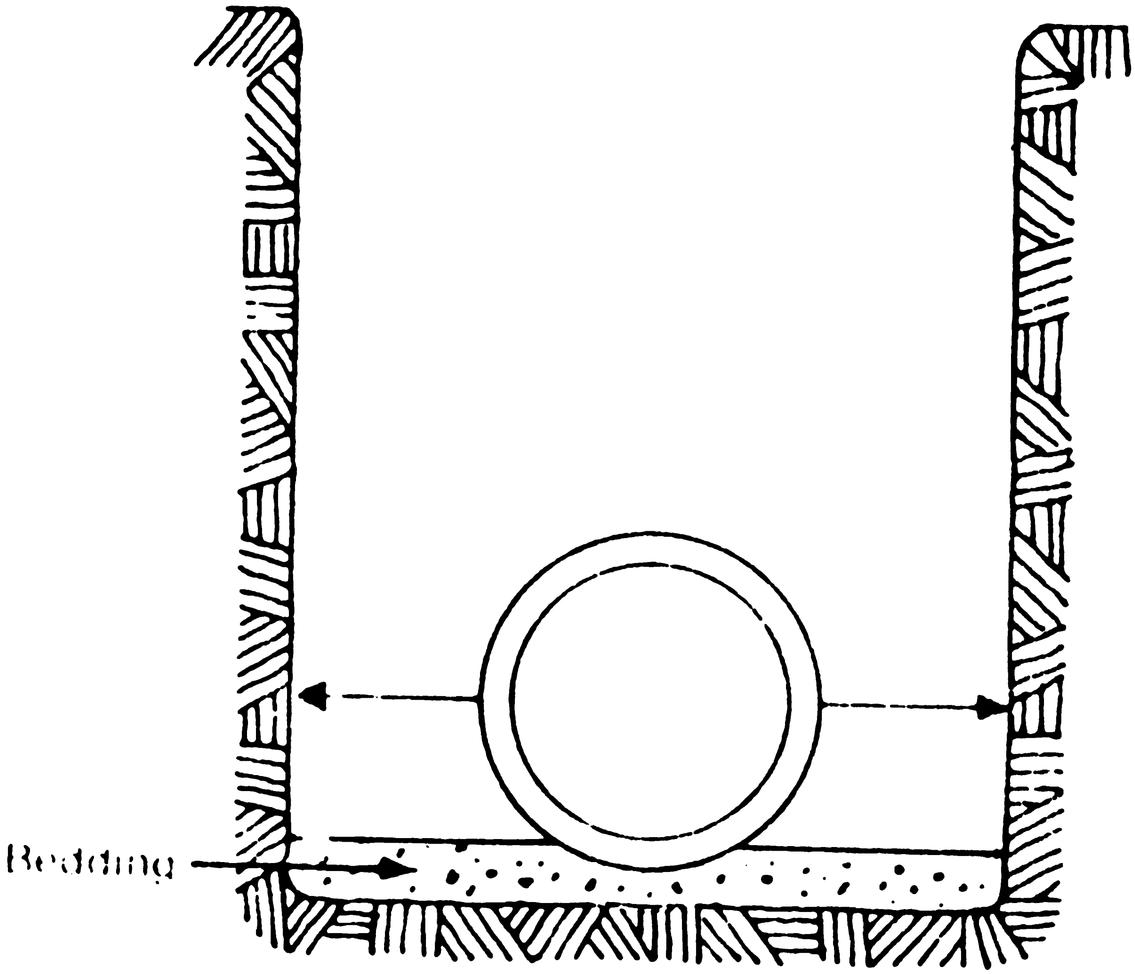

Figure 4-18.--Placement of waterline in trench.

bottom of the trench to provide a cushion for the pipe. Failure to do this may result in the pipe resting on a sharp point of rock, making it subject to breakage under the weight of the backfill load, surface load, or earth movements (Cast Iron Pipe Research Association, 1952).

(4) Dewater trench.

The trench bottom for the pipe should be smooth and dry so that the pipe can be uniformly supported along its length (Cast Iron Pipe Research Association, 1952). High ground water in the excavated trench interferes with the proper placement of the pipe. In areas of this occurrence, well-point systems or backhoes are commonly used to pump out this water, and thereby temporarily lower the local ground water table.

(5) Wrap pipe with polyethylene.

Research has shown that in certain types of soils corrosion of uncoated cast iron pipe may occur (Romanoff, 1957). Corrosion is a physical and biochemical process which converts iron into its compounds resulting in putting holes in it and eventual service failure of the pipe. The potential corrosivity of a soil can be estimated by the following factors: (1) resistance to flow of electrical current, (2) total acidity, (3) soil drainage, (4) soil texture, and (5) conductivity of saturation extract (SCS, USDA, 1978). Soils are then assigned to one of three classes of corrosivity: low, moderate, or high. This information along with local knowledge of the service history of cast iron pipe can indicate the likelihood of potential corrosion.

Once having established that a soil is potentially corrosive to cast iron pipe, it is necessary to provide adequate means of pipe protection. Several pipe protection procedures have been studied over a long period of time, such as cathodic protection, factory-applied coatings, or cement armour coatings. For the most part, these are uneconomical due to either high installation costs or the continuing need for maintenance (Romanoff, 1964). Research conducted by the Cast Iron Pipe Research Association over a 15-year period (Wagner, 1964; Smith, 1968) indicates that effective and economical corrosion protection can be provided by encasing the pipe during installation with a loose external sleeve of polyethylene. Hundreds of thousands of feet of cast iron water pipe are now protected by this polyethylene tubing in extremely corrosive soils.[22]

(6) Tamp backfill by hand.

Backfilling of the pipe trench after pipe installation usually follows as closely as possible to eliminate the problem of the pipe shifting out of line (Cast Iron Pipe Research Association, 1952). Generally, mechanical rolling equipment is used to compact the backfill, thereby saving labor costs. However, where the pipe is laid in undulating or hilly topography, hand labor is needed to insure that there is thorough compaction under and on each side of the pipe to provide support free from voids.

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[22]Personal communication with George Bogs, General Manager, U.S. Pipe and Foundry Company, Birmingham, Alabama.

This lessons the possibility of the pipe shifting out of line due to the backfill slipping downhill. Erosion control measures in the trench area can also help prevent soil losses. Maintenance costs, however, obviously increase as slope gradient increases.

(7) Thrust blocking and anchoring.

In addition to hand tamping of the backfill, metal anchors and concrete thrust blocks are necessary where water pipes are installed in steep topography to insure that the pipe does not slip downhill with the backfill (Cast Iron Pipe Research Association, 1952). Concrete thrust blocks and metal anchors are used to align and support the pipe firmly under these conditions. Installation of these materials, however, require considerable labor and adds to construction costs significantly.

Cost of Corrective Measures

Table 4-16 presents the estimated costs of applying different corrective measures to overcome soil limitations for residential water lines in Eaton County, Michigan. The figures listed in this table are generalized estimates in 1978 dollars of the costs per linear foot required to install an 8-inch diameter pipe. They are clearly not intended to eliminate the need for cost estimating on a site-by-site basis. The dollar amount listed for each soil is the mean of the range in costs (Appendix Table C5) for installing these different corrective measures. These were computed from cost analyses of completed residential water lines in the county,

Table 4-16. Soil limitations and estimated costs of applying different corrective measures for residential waterlines in Eaton County, Michigan

Soil Map Unit	Soil Limitation	Initial Cost per Linear Foot ($1978)	Corrective Measure
Adrian muck	Severe	17.00	A,B,D,E
Bixby loam, 0 to 3 percent slopes	Moderate	11.25	A
Borrow land	Properties too variable to be rated		
Boyer loamy sand, 0 to 6 percent slopes	Severe	11.25	A
Boyer loamy sand, 6 to 12 percent slopes	Severe	13.75	A,F
Boyer sandy loams, 0 to 6 percent slopes	Severe	11.25	A
Boyer sandy loams, 6 to 12 percnet slopes	Severe	13.75	A,F
Boyer-Spinks loamy sands, 12 to 18 percent slopes	Severe	16.75	A,F
For Spinks part see Spinks series			
Brady-Bronson sandy loams, 0 to 3 percent slopes	Severe	15.25	A,D,E
For Bronson part see Bronson series			
Bronson series	Severe	12.75	A,D
Mapped only in a complex with Brady soils			
Capac loam, 0 to 3 percent slopes	Severe	15.25	A,D,E
Capac-Marlette loams, 1 to 6 percent slopes	Slopes	15.25	A,D,E
For Marlette part see Marlette series			
Cohoctah fine sandy loam, frequently flooded	Severe	15.25	A,D,E
Colwood loam	Severe	15.25	A,D,E
Colwood loam, depressional	Severe	15.25	A,D,E
Edwards muck	Severe	17.00	A,B,D,E
Gilford sandy loam	Severe	15.25	A,D,E

Table 4-16. Continued

Soil Map Unit	Soil Limitation	Initial Cost per Linear Foot ($1978)	Corrective Measure
Hillsdale sandy loam, 2 to 6 percent slopes	Slight	11.25	A
Hillsdale sandy loam, 6 to 12 percent slopes	Moderate	13.75	A,F
Houghton muck	Severe	17.00	A,B,D,E
Kibbie fine sandy loam, 0 to 3 percent slopes	Severe	15.25	A,D,E
Lenawee silty clay loam, depressional	Severe	15.25	A,D,E
Marlette loam, 2 to 6 percent slopes	Moderate	11.25	A
Marlette loam, 6 to 12 percent slopes	Moderate	13.75	A,F
Marlette clay loam, 6 to 12 percent, severly eroded	Moderate	13.75	A,F
Marlette loam, 12 to 18 percent slopes	Severe	16.75	A,F
Marlette loam, 18 to 25 percent slopes	Severe	16.75	A,F
Matherton loam, 0 to 3 percent slopes	Severe	15.25	A,D,E
Metamora-Capac sandy loam, 0 to 4 percent slopes	Severe	15.25	A,D,E
For Capac part see Capac series			
Metea			
Mapped only in complex with Spinks soils			
Metea part of Spinks-Metea loamy sands, 0 to 6 percent slopes	Slight	11.25	A
Metea part of Spinks-Metea loamy sands, 6 to 12 percent slopes	Moderate	13.75	A,F
Oshtemo sandy loam, 0 to 6 percent slopes	Severe	11.25	A
Oshtemo sandy loam, 6 to 12 percent slopes	Severe	13.75	A,F

Table 4-16. Continued

Soil Map Unit	Soil Limitation	Initial Cost per Linear Foot ($1978)	Corrective Measure
Owosso-Marlette sandy loams, 1 to 6 percent slopes	Moderate	11.25	A
For Marlette part see Marlette series			
Owosso-Marlette sandy loams, 6 to 12 percent slopes	Moderate	13.75	A,F
For Marlette part see Marlette series			
Owosso-Marlette sandy loams, 12 to 18 percent slopes	Severe	16.75	A,F,G
For Marlette part see Marlette series			
Palms muck	Severe	17.00	A,B,D,E
Parkhill loam	Severe	15.25	A,D,E
Sebewa loam	Severe	15.25	A,D,E
Shoals-Sloan loams	Severe	15.25	A,D,E
For Sloan part see Sloan series			
Sloan Series	Severe	15.25	A,D,E
Mapped only in complex with Shoals Series			
Spinks loamy sand, 0 to 6 percent slopes	Severe	11.25	A
Spinks-Metea loamy sands, 0 to 6 percent slopes	Severe	11.25	A
For Metea part see Metea series			
Spinks loamy sand, 6 to 12 percent slopes	Severe	13.75	A,F
Spinks-Metea loamy sands, 6 to 12 percent slopes	Severe	13.75	A,F
For Metea part see Metea Series			

Table 4-15. Continued

Soil Map Unit	Soil Limitation	Initial Cost per Linear Foot ($1978)	Corrective Measure
Spinks part of Boyer-Spinks loamy sands, 12 to 18 percent slopes	Severe	16.75	A,F,G
Tuscola fine sandy loam, 0 to 4 percent slopes	Severe	12.75	A,D
Wasepi sandy loam, 0 to 3 percent slopes	Severe	12.75	A,D
Wasepi sandy loam, bedrock variant, 0 to 3 percent slopes	Severe	18.25	A,C,D
Winneshiek silt loam, 0 to 3 percent slopes	Moderate	12.75	A,D

A=Install pipe with pipe trencher
B=Excavate peat and muck
C=Excavate rock
D=Dewater trench
E=Wrap pipe with polyethylene
F=Tamp backfill by hand
G=Thrust blocking and anchoring

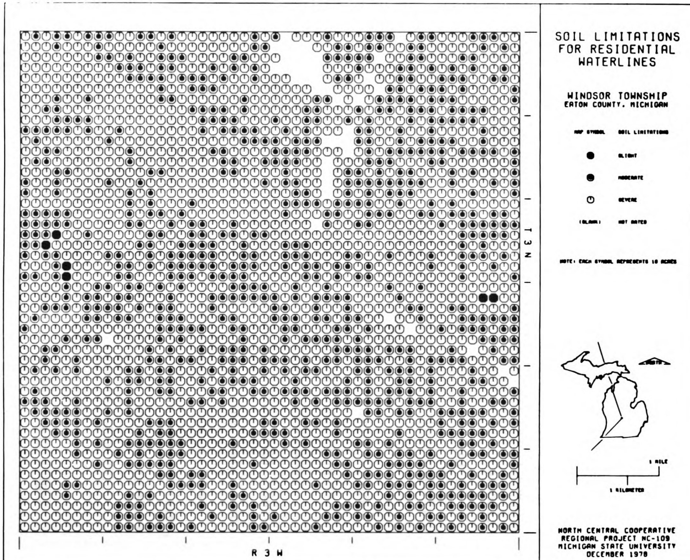
obtained from public works departments, construction trade organizations, engineers, and others.

The average initial costs for installing the different corrective measures on these soils in the county ranges from $11.25 to $18.25 per linear foot of pipe. These data clearly indicate the need for additional investment for organic soils (Adrian, Edwards, Houghton, Palms) and those shallow to bedrock (Wasepi, bedrock variant). These soils have among the highest costs for water line construction of all the soils listed in Table 4-15. The organic soils require an expenditure of approximately $17.00 per linear foot which is 51.1 percent greater than the cost required to install similar waterlines in soils with only slight limitations. Soils shallow to bedrock require approximately $18.25 to install similar water lines, an increase of 62.2 percent over the costs on soils with slight limitation. This again clearly demonstrates the reason organic soils and those shallow to bedrock should be avoided for water line construction, if at all possible.

Computer Output

Figure 4-19 illustrates the locations of areas with soil limitations for residential water lines in Windsor Township, Eaton County, Michigan. The basic format of this computer-generated map is again essentially the same as those previously presented in this chapter. The darkest or black octagons represent areas which have only slight limitations for this use, while those areas with severe limitations are represented by unshaded or white

Figure 4-19.--Computer-drawn interpretive map illustrating soil limitations for residential waterlines in Windsor Township.


SOIL LIMITATIONS
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DECEMBER 1978

octagons. Areas with moderate soil limitations are thus represented by octagons which are intermediate in tone. Blank cells represent unrated borrow land and water areas.

A visual examination of the map indicates that much of the land in the township has severe limitations for this land use. The most prominent area again straddles the "Old Maid Swamp" (see Figure 1-3) in the northeast quadrant of the township. This area consists, as previously mentioned, of nearly level, poorly and very poorly drained mucky and loamy soils (i.e., Adrian, Colwood, Edwards, Gilford, Houghton, Palms, Parkhill, etc.) located in ancient glacial drainageways. Another large area with similarly rated soils (i.e., Capac, Gilford, Houghton, Sebewa, etc.) is located in the extreme southwest corner of the township (Figure 4-18). A third area on the map with similar kinds of soils is located in the south-central portion of the township in the vicinity of the upper Skinner Drain Extension (Figure 1-3). Soils in these three areas present serious problems for the installation of residential water lines, although the organic soils in these areas have again more difficult soil limitations to overcome (i.e., peat and muck at great depths, high water tables, corrosive, etc.) requiring additional corrective measures (Appendix Table F5), thereby increasing the cost of waterline construction.

The spatial distribution of soil areas with only slight or moderate limitations for residential waterlines is also well illustrated in Figure 4-19). These areas are generally scattered throughout the map. A notable area is located in the west-central portion of the township, adjacent to U.S. Highway 27 (Temporary Interstate 69) and in the vicinity of West Windsor (Figure 1-2). A study of the soils map indicates that Bixby, Hillsdale, Marlette, and Owosso soils dominate this area's landscape. These well and moderately drained soils have deep depths to seasonal water tables insuring that trenches dug in these soils are unlikely to be wet. In addition, their potential corrosivity of cast iron pipes is low.

Table 4-17 shows the proportionate extent and approximate acreage of soils in Windsor Township with different degrees of limitations for residential waterlines. These calculations are based on the number of cells in each category (slight, moderate, severe, unrated) as plotted in Figure 4-19. According to the information presented on the right side of this table, 69, 8,525, and 14,031 acres have slight, moderate, and severe limitations for this land use, respectively. These data then indicate that only 37.3 percent of the land (8,594 acres) in the township has slight or moderate limitations for residential waterlines, and is therefore suitable for use without special pipeline installation measures, while more than half of the land area (60.9 percent or 14,031) has severe soil limitations for this land use, requiring usually more costly corrective measures.

Significant changes can occur in the amount of suitable land for this nonagricultural land use by applying different corrective measures on soils with moderate or severe limitations.

Table 4-17. Proportionate extent and approximate acreage of soils classified by soil limitations and potentials for residential waterlines in Windsor Township, Eaton County, Michigan.

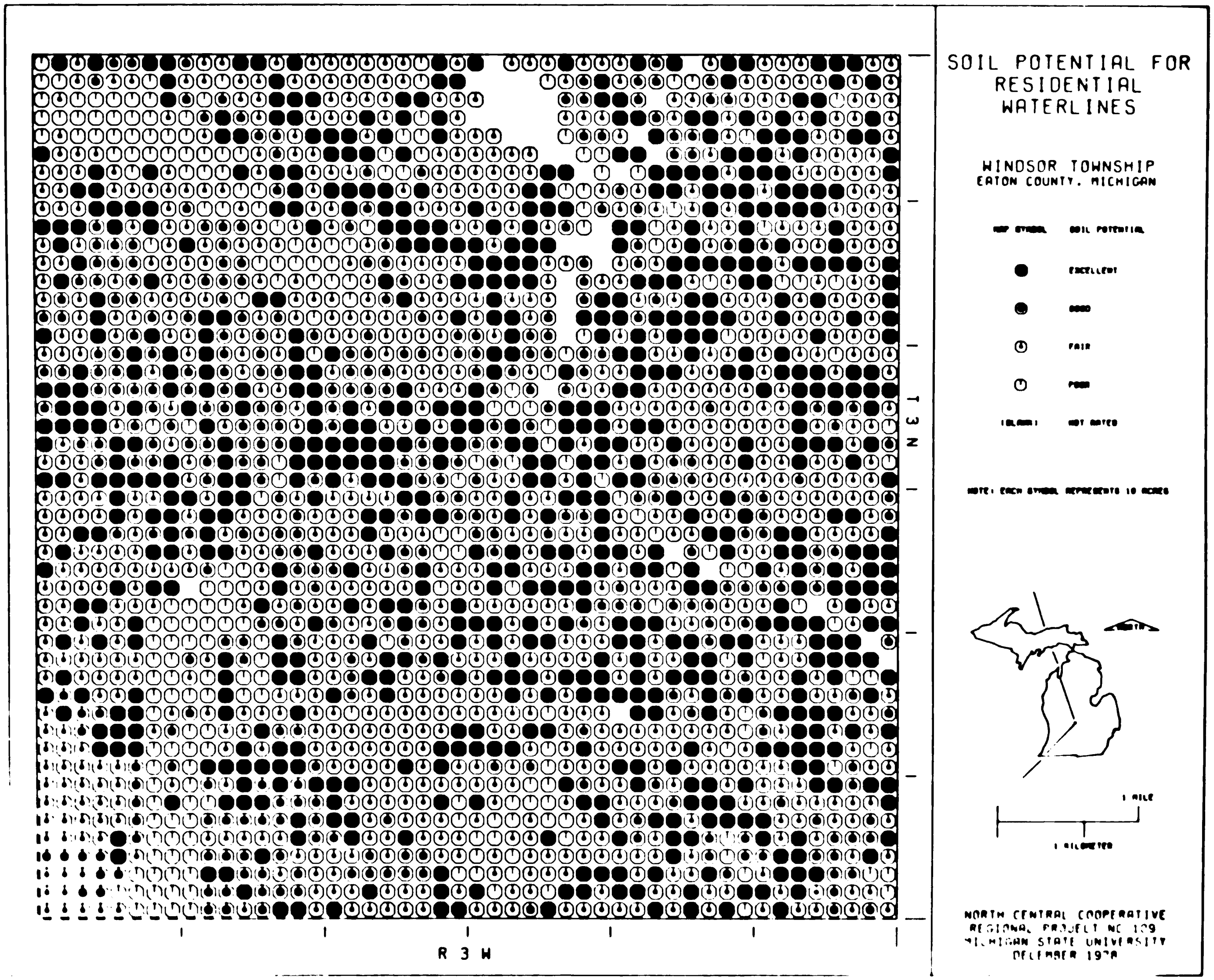
Degree of Soil Limitation	Soil Potential Rating: Excellent		Good		Fair		Poor		Unrated		Total	
	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres
Slight	0.3	69	-	-	-	-	-	-	-	-	0.3	69
Moderate	27.0	6221	10.0	2304	-	-	-	-	-	-	37.0	8525
Severe	3.9	899	5.8	1336	40.1	9239	11.1	2557	-	-	60.9	14031
Unrated	-	-	-	-	-	-	-	-	1.8	415	1.8	415
Total	31.2	7189	15.8	3640	40.1	9239	11.1	2557	1.8	415	100.0	23040

NOTE: Calculations are based on Figures 4-19 and 4-20 (2304 cells, 10 acres per cell).

Table 4-17 shows the proportionate extent and approximate acreage of soils in Windsor Township classified according to their potential for residential waterlines. According to the information presented along the bottom of this table, 7,189, 3,640, 9,239, and 2,557 acres have excellent, good, fair, and poor potential, respectively, for this land use. Further study of these data indicates that out of the 14,031 acres of land in the township, which are rated as having severe soil limitations, 81.8 percent of this land area has excellent, good, or fair potential for residential waterlines after installation of corrective measures. This is a significant increase of 135 percent or 11,474 acres in the amount of land that might be suitable for residential waterlines, provided that the proper corrective measures are applied to each soil (Appendix Table F5). Just as significant is the fact that only 11.1 percent of the land area in the township has soils with poor potential, while approximately 31.2 and 16.8 percent have soils with excellent and good potential, respectively.

Figure 4-20 shows the location of soils with different potentials for residential waterlines in Windsor Township. Notice that only a few areas on the map have high concentrations of soils with poor potential for this land use. One such area is located in the northwest quadrant of the township straddling the "Old Maid Swamp." Another elongated area is situated in the southwest quadrant of the township along the King and Carleton drains (Figure 1-3). Several other areas of minor acreages are located

Figure 4-20.--Computer-drawn interpretive map illustrating soil potential for residential waterlines in Windsor Township.


SOIL POTENTIAL FOR
RESIDENTIAL
WATERLINES
WINDSOR TOWNSHIP
EATON COUNTY, MICHIGAN
MAP SYMBOL
SOIL POTENTIAL
EXCELLENT
GOOD
FAIR
POOR
(BLANK)
NOT RATED
NOTE: EACH SYMBOL REPRESENTS 10 ACRES
1 MILE
1 KILOMETER
T 3 N
R 3 W
NORTH CENTRAL COOPERATIVE
REGIONAL PROJECT NC 129
MICHIGAN STATE UNIVERSITY
DECEMBER 1978

near the Grand River (Figure 1-3). These areas, as discussed previously, consist of very poorly drained organic soils or alluvial soils (Cohoctah, Sloan) requiring costly excavation and trench drainage procedures (Appendix Table F5 and Table 4-15). Although corrective measures can be applied to overcome some of their limitations, these soils are subject to flooding, and consequently are among the poorest choices for building sites in the township.

Figure 4-20 also shows that much of the township has soils with excellent, good, or fair potential for residential waterlines. By visually comparing Figure 4-19 with the generalized land use and cover map for the same area (Figure 4-9), it is clear that a degree of incompatability and potential land use conflict exists. This overlap is most prevalent in the west-central and southwest portions of the township where large blocks of contiguous soils areas have excellent and good potential for residential waterlines. The extension of waterlines in these previously agricultural and wooded areas would increase pressures for urban development unless careful planning is begun to preserve both good land for food and fiber production, as well as providing land for urban development.

Time/Cost Parameters for Preparation and Display of Soil Potential Ratings

Approximately one year was spent in collecting the necessary data needed for preparing the soil potential ratings for the five urban land uses discussed here in Eaton County. For nearly half this time, twenty hours a week were spent, while throughout the remaining six months, the time spent was increased to forty hours a week. The following tasks were undertaken during this time span: (1) identification of technical experts to provide data on kinds of corrective measures needed; (2) compile list of corrective measures; (3) compile costs of corrective measures; (4) determine continuing limitations remaining after corrective measures are applied; (5) record data for soils in Eaton County; (6) enter costs for corrective measures and rating of continuing limitations for each soil into a computer disk file; (7) generate soil potential indexes using SCALE computer program; (8) array soils into soil potential classes based on intervals generated by use of JENKS computer program; and (9) prepare computer display maps using PLOTTERMAP program.

The Windsor Township master file was obtained from the MSU Remote Sensing Project, who spent nearly $1,500 for encoding of data and creation of the master file.[23] The investigator manipulated the file, at a cost of approximately $150, to allow inclusion of the collected data on soil potentials for the five different land uses. Computation costs using the SCALE and JENKS program were approximately another $150. The costs for producing each computer-plotter map were about $35 per map, including computer

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[23]Personal communication with Steven Tilmann, Research Associate, Department of Resource Development, Michigan State University, East Lansing, Michigan.

and plotter time. The costs involved in using permanent files, tape purchase, and unsuccessful runs are not included in these figures.

Summary

This chapter presented the data collected in the study and discussed the results obtained for each of the five nonagricultural land uses. Recommended corrective measures for overcoming soil limitations were identified for soils in Eaton County, Michigan. Estimated costs of applying these different corrective measures for each land use were presented. The soil potential ratings generated in the study and soil limitation ratings obtained from the county soil survey were displayed in computer-generated maps. This facilitated a visual and statistical understanding of these soil interpretations for the different nonagricultural land uses in Windsor Township.

CHAPTER V

SUMMARY AND CONCLUSIONS

The purpose of this final chapter is to summarize the entire study, present highlights of major findings, and discuss their implications. In addition, limitations of the study are pointed out and suggestions for further research are discussed.

Summary of the Problem

Over the last decade, soil interpretations for nonagricultural land uses have been presented largely through identification of the degree and kind of soil limitation that imposes hazards, risks, or obstructions for an intended use. A three-class system has been commonly used, employing the terms, "slight," "moderate," and "severe," to describe a sequence of increasing difficulties encountered in soil performance for a specified use. Unfortunately, however, these limitation ratings have not provided the soil survey user with adequate information about the performance and cost of potential practices for overcoming soil limitations in specific kinds of soil. It has been all too common for a community to survey its soils only to find that almost all soil areas within its boundaries have severe limitations for a variety of important land uses. More and more, planning officials and resource developers are requiring details of designs or design criteria and estimates of costs for structures and management practices needed to overcome soil limitations in specific kinds of soil used for a variety of nonagricultural land uses.

At the outset of this study, the concept of soil potentials was being strongly considered by the U.S. Soil Conservation Service as a new approach to help prepare these kinds of soil interpretations for survey users. This pilot study in Eaton County, Michigan was primarily designed to develop and test a general set of techniques which would help generate these ratings of soil potential for nonagricultural land uses and also help to communicate these interpretations to soil survey users. The general objective was further defined in terms of several more specific research objectives:

1. Survey the relevant literature to locate existing methods and techniques used to generate soil potential ratings and computerized-interpretive soil maps.

2. Describe and identify the kinds of practices or alternatives that may be used to overcome soil limitations, their costs, and continuing limitations that remain after corrective measures have been applied.

3. Develop a set of computer-assisted procedures to help prepare soil potential ratings for several major nonfarm land uses.

4. Demonstrate the use of a computer software system to assist in the retrieval, manipulation, and display of stored soil potential ratings.

5. Make recommendations concerning future needs and actions on the concept of soil potential.

The technique developed in the study were illustrated by a test conducted in Windsor Township, Eaton County, Michigan, an urbanizing area which had a newly completed soil survey report.

Soil interpretations based on the soil potential approach were made of the following five urban land uses: (1) septic tank filter fields for on-site waste disposal; (2) residential roads and streets; (3) residential dwellings with sanitary sewers and without basements; and (5) excavations for residential waterlines.

Summary of the Methods

A systematic procedure was employed in this study to numerically rate a soil's potential for the several different urban land uses in Eaton County, Michigan. A thorough investigation of books, articles, studies, and interviews were undertaken to identify construction designs and development costs needed to overcome soil limitations. Professional trade associations and individual contractors, as well as state, regional, and local governmental agencies, were contacted to obtain this necessary information. Construction cost data were derived from nationally known reference texts or averages of actual case studies supplied by local contractors and adjusted for prices of materials and labor existing in the Lansing area in 1979.

Estimates were also made of any continuing limitations remaining after designs or treatments have been installed to correct soil hazards. A three-class, employing the terms, "slight," "moderate," and "severe," was used to indicate the severity of these continuing limitations. The rating of a given kind of soil in such a system signified not only the degree to which soil hazards have been corrected or overcome by special construction designs or treatments, but also, in general terms, a prediction of the cost and level of maintenance required for upkeep of these special treatments. Assignment of these qualitative ratings to each soil was made with the assistance of technical experts familiar with the construction and maintenance difficulties encountered with each particular urban land use.

Data collected in the study were entered into an existing natural resource inventory system for Windsor Township. This data bank contained an extensive file of soils and natural resource data which were previously assembled by the Remote Sensing Project at Michigan State University using a ten-acre dot grid overlayed onto several different factor maps. A computer software system, called RAP (Resource Analysis Package), was used to assist in the retrieval, manipulation, and analysis of this spatially-encoded data.

The ratings of soil potential for the five land uses were generated with the aid of a multi-dimensional scaling option available in RAP. For the purposes of this study, soil potential for a specific land use was defined as a function of the costs of construction practices or treatments required to overcome soil limitations and the severity of any continuing limitations remaining after treatment.

Briefly, the multi-dimensional scaling technique used in this study consisted of establishing an n-space, where n is the number of factors in the analysis. The numerical value of each factor established a point for it in the n-space. The Euclidian distance between that point and a point representing an optimum condition set for soil potential was the soil potential index. The resulting interpoint distances obtained were then normalized to cover the conventional range of 0 to 100. The index was then inverted so that soils with the highest soil potential would have large numbers, while those with the lowest soil potential would have small numbers. Each component of a soil complex was rated separately with the final rating of the entire unit determined by multiplying the rating of each by its estimated areal extent in the map unit and tallying these index values.

The final soil potential index values were then used to assign each soil to one of four qualitative classes of soil potential, employing the terms, "excellent," "good," "fair," and "poor." The JENKS grouping program, modified to run interactively on the University CDC 6500 computer, was then employed by this researcher to select statistically optimal class intervals for grouping soils in Eaton County into each of these four rating classes. The soil potential ratings for each land use were then entered to computer disk storage for subsequent analysis. A computer mapping program available in RAP was used to construct interpretive maps illustrating soil potentials and limitations for each of the five chosen urban land uses in this study.

Summary of the Findings

Information obtained during the course of the study provided numerous findings concerning the kinds of practices or alternatives that may be used to overcome certain soil limitations, their costs, and continuing limitations that remain after the corrective measures have been applied to the five chosen non-agricultural land uses in Eaton County, Michigan. In addition, computer-generated interpretive maps drawn for Windsor Township both demonstrated the unique graphic capabilities of the RAP system and facilitated a visual understanding of soil interpretations for these different non-agricultural land uses. These findings are briefly summarized for each of these five land uses in the sections which follow.

(1) Findings Relating to Septic Tank Filter Fields for On-Site Waste Disposal.

Of Windsor Township's total of 23,040 acres, only 9,816 or 42.6 percent of the land area has slight or moderate soil limitations for septic tank filter fields, and is therefore suitable for use of conventional septic tank-soil absorption systems. More than half of the land area (55.6 percent or 12,810 acres) has severe soil restrictions for these same systems. Based on the data collected in this investigation, there are two feasible alternatives, used in the study area, to conventional septic tank filter field systems. These are elevated sand mound systems and sewage holding tanks.

The average initial costs in 1978 for installing corrective measures on different soils for on-site sewage disposal in Eaton

County, Michigan ranged from about $800 to $3,000. Soils with slight limitations for this land use required an initial investment of only about $800 to $1,050 for installation of conventional septic tank disposal systems. Soils with moderate limitations required an expenditure of about $1,000 to $2,000 to install similar systems. Initial costs for soils with severe limitations are much higher ranging from about $1,250 to $3,000.

With the advent of innovative new technologies to overcome or treat moderate and severe soil limitations, such as high seasonal ground water and slow percolation rates, significant changes may occur in the amount of land suitable for on-site waste disposal. Results from this study indicated that out of the 12,810 acres of land in Windsor Township which are rated as having severe soil limitations for this land use, over 11 percent or 2,857 acres may have good or fair soil potential, assuming that modifications of conventional systems and mound systems are installed. This is a significant increase of 32 percent or 2,857 acres in the amount of land that may be suitable for on-site sewage disposal in the township.

(2) Findings Relating to Residential Roads and Streets.

Based on the data provided in the county soil survey report, there are 9,769 acres or 42.4 percent of the land in Windsor Township which has slight or moderate limitations for residential roads and streets. These areas are suitable for use without special road designs. More than half of the land area (55.6 percent or 12,856 acres) has severe limitations for this land use, and usually requires more costly corrective measures. The following four kinds of corrective measures commonly used in Eaton County to overcome problem soil conditions for residential roads and streets: increase pavement thickness, excavate peat and muck, add fill to raise grade of roadway, or cutting and filling.

The average initial costs for installing these corrective measures on different soils in Eaton County, Michigan in 1978 ranged from about \$15.50 to \$44.50 per linear foot of roadway (30-feet wide). Organic soils had the highest costs for roadbed construction. In fact, their initial construction costs are nearly twice as much as those of the most costly mineral soils. The data also indicated increased costs of residential roadway construction on sloping soils. There is an approximately 35 percent increase in the cost of construction for a road on an 18 to 25 percent slope compared to one on a 2 to 8 percent slope. This increase is due mainly to the enormous volume of soil material that must be moved in order to provide a suitable road grade for motorized vehicles.

Data from the study indicated that significant changes can occur in the amount of suitable land for residential roads and streets by applying the different corrective measures on soils with moderate or severe soil limitations. Results showed that out of the 12,856 acres which have severe soil limitations for this land use, 83.7 percent of the land in the township has excellent, good, and fair potential for residential roads and streets. This is a significant increase of almost 111 percent or 10,760 acres in the amount of land that might be suitable for this land use in Windsor Township if the proper corrective measures are applied on these soils.

(3) Findings Relating to Residential Dwellings With Sanitary Sewers and Basements.

There are 7,189, 2,604, and 12,832 acres of land in Windsor Township with slight, moderate, and severe soil limitations (respectively) for residential dwellings with basements. These data indicate that only 42.5 percent of the land has slight or moderate limitations, and is therefore suitable for use without special foundation designs or additional grading or drainage. The remaining land area (55.7 percent or 12,832 acres) which has severe soil limitations requires more costly corrective measures. The following corrective measures are currently commonly used by building contractors in Eaton County, Michigan: alternative basement construction designs, add fill to raise grade of site, excavate rock, excavate peat and muck, cuts and fills, or improve surface drainage.

The average initial costs for installing these different corrective measures on soils in Eaton County, Michigan in 1978 ranged from about $5,200 to $9,700 per dwelling site. Soils with slight limitations only require an initial investment of about $5,200 for installation of conventional basements, while those soils with moderate limitations require and additional expenditure of about $550, primarily because of the increased site grading required. The initial cost for soils with severe limitations are higher, ranging from about $5,950 to $9,700 per dwelling site. The organic soils mapped in the county have the highest costs for home construction with basements. In fact, their costs are almost 87 percent more than the costs required to build dwellings with basements on soils having only slight limitations for this use.

Applying different corrective measures to soils with severe soil limitations for residential dwellings with basements may increase the amount of land suitable for this use. Data from this investigation indicated that out of the 12,833 acres of land in the township rated as having severe limitations for this land use, approximately 84.2 percent of this land area has excellent, good, or fair potential for dwellings with basements. This is a significant increase of about 106 percent or 10,413 acres in the amount of land suitable for this land use in the township, provided that the proper corrective measures are applied to each soil.

(4) Findings Relating to Residential Dwellings With Sanitary Sewers and Without Basements.

There are 461, 9,331, and 12,832 acres of land in Windsor Township with slight, moderate, and severe limitations for residential dwellings without basements, respectively these data indicate that only 42.5 percent or 9,792 acres in the township has slight or moderate limitations for this land use, and is therefore suitable for use without special drainage systems in the slab bed or yard.

More than half of the land area (55.7 percent or 12,832 acres) has severe soil limitations usually requiring more costly corrective measures for overcoming soil limitations. The following kinds of corrective measures are commonly used by building contractors in Eaton County, Michigan: reinforce slab, add fill to raise grade of site, excavate peat and muck, cutting and filling, drainage of footing and slab, or improve surface drainage.

The average initial costs for installing these different corrective measures on soils in Eaton County, Michigan in 1978 ranged from about \$3,250 to \$5,400 per dwelling site. Soils with slight limitations only require an initial investment of about \$3,250 for installation of slabs-on-grade. Those soils with moderate limitations require an additional expenditure of about \$500, primarily because of the increased site grading required. The initial costs for soils with severe limitations are higher ranging from about \$3,750 to \$5,400. The organic soils mapped in the county have the highest costs for home construction without basements. In fact, their costs are nearly 66 percent greater than those required to build similar dwellings without basements on soils having only slight limitations for this use.

Applying different corrective measures to soils with severe limitations for residential dwellings without basements may increase the amount of suitable land for this use. Data from this study indicates that out of the 12,832 acres of land in the township rated as having severe limitations for this land use, 80.8 percent of this land area has excellent, good, or fair potential for dwellings without basements. This is a significant increase of 111 percent or 10,368 acres in the amount of land that might be suitable for this land use in the township, provided that the proper corrective measures are applied to each soil.

(5) Findings Relating to Residential Waterlines.

There are 69, 8,525, and 14,031 acres of land in Windsor Township which have slight, moderate, and severe limitations for residential waterlines, respectively. These data indicate that only 37.3 percent or 8,594 acres of land in the township has slight or moderate limitations for residential waterlines, and is therefore suitable for use without special pipeline installation measures. More than 60 percent of the land area (60.9 percent or 14,031 acres) has severe soil limitations for this land use requiring more costly corrective measures for drainage or slope. Based on information provided by local contractors in the Lansing area, the following are corrective measures commonly used on soils in Eaton County to overcome these problem soil conditions: install waterpipe with pipe trencher, excavate peat and muck, excavate rock, dewater trench, wrap pipe with polyethylene, tamp backfill by hand, or thrust blocking and anchoring.

The average initial costs for installing the different corrective measures on soils in Eaton County, Michigan in 1978 ranged from about $11.25 to $18.25 per linear foot. Organic soils and those shallow to bedrock have the highest costs for waterline construction. The organic soils require an expenditure of $17.00 per linear foot which is about 51.1 percent greater than the cost required to install similar waterlines in soils with only slight soil limitations. Soils shallow to bedrock require an expenditure of $18.25 per linear foot to install similar waterlines, an increase of about 62.3 percent over the costs required on soils with slight limitations.

Data gathered during the study revealed that significant changes may occur in the amount of land suitable for residential waterlines by applying different corrective measures on soils with moderate or severe soil limitations. There are 7,189, 3,640, 9,239, and 2,557 acres which have excellent, good, fair, and poor soil potential for this land use, respectively. This indicates that out of the 14,031 acres of land in Windsor Township which use, approximately 81.8 percent of this land area or 11,474 acres have excellent, good, or fair potential for residential waterlines. This is a significant increase of about 135 percent or 11,474 acres in the amount of land that might be suitable for this land use, provided that the proper corrective measures are applied to each soil in Windsor Township.

Uses and Limitations of This Study

Since soils are among our most valuable natural resources they should be used in the most rational manner possible. This investigation has been designed to develop a set of procedures by which ratings of soil potential can be generated, stored, and displayed in computer-drawn interpretive maps. The techniques and analytical results developed in this investigation and illustrated by a pilot study in Windsor Township exhibit great practical usefulness and applicability as planning and educational tools which may help improve the land use decisions of both private and public resource developers. Although this investigator has not as yet made a definitive study in this regard, there are several important areas for which this study's work is particularly well suited.

Assistance in State, Regional, and Local Growth Policies

Federal land use legislation has failed to clear both houses of Congress since 1972. In the absence of a strong national land use policy, numerous state, regional, and local planning agencies are attempting to develop effective land use and growth management policies to help accommodate the nearly 50 million more Americans expected in the year 2,000 than there were in 1970, and yet also preserve our precious environmental quality. The legislature of the State of Florida, for example, has passed legislation[24] which requires local governments throughout the state to prepare comprehensive plans detailing how each community will accommodate the influx of population expected in the next decade. Planners and decision-makers in several Florida counties are already beginning to utilize soil potential ratings for

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[24]"Florida Local Government Comprehensive Planning Act of 1975" (Chapter 75-257, Laws of Florida, 1975).

agricultural and urban land uses as a basis for developing "growth management plans" to reserve their best soils for agriculture and to put houses and sewage disposal systems, for example, on somewhat less satisfactory soils in order to preserve critical agricultural lands important to both the state and local economies. From the author's brief discussions with these planners, it seems clear that the computer-based techniques developed in this study can be used to great advantage by these planning officials to aid in their drafting (and subsequent updating) of local comprehensive plans.

Private/Corporate Land Use Decisions

Corporate and private interests in the United States have traditionally been directly concerned with resource developments involving the use of land, such as housing subdivisions, shopping centers, recreational complexes, industrial parks, and utilities. Techniques developed in this study for generating soil potential ratings can be useful to these groups for determining potential optimal sites and their cost of development based on soils information for a given land use. These sites can later be investigated thoroughly by on-site field evaluations for detailed engineering designs and cost estimating. This process can help save valuable time and money for these firms, or their consultants for site analysis, and thus improve the locational decisions of private resource developers, as well as determining future investment plans and land management strategies.

Cooperative Extension Service

Soil interpretation is a way of simplifying what soil scientists know about soil properties and then relating them to the possible uses of the soil. Over the past decade Soil Extension Specialists have presented soil interpretations largely through ratings of soil limitations. The increased availability of soil survey reports and the remarkable increase in background knowledge of today's users requires Soil Specialists to expand soil interpretations beyond simple listings of soil limitations for different land uses and discuss possible management alternatives for problem soils, their costs, and what continuing limitations, if any, remain after these practices or devices are in place. This calls for more sophisticated soil survey educational programs by Cooperative Extension. The techniques developed in this study to generate and display soil potential ratings will be useful for these specialists to meet this educational challenge.

Although in the past few paragraphs discussion has centered about the potential uses of the results of this study, there are only a number of limitations that merit special attention. First, like most studies dealing with soil survey interpretations, the soils information herein should be cautiously used only for general planning purposes. These interpretations are not intended, nor should they be used, to eliminate the need for on-site sampling, testing, or detailed field investigation for the design of engineering structures. Soils are variable and, due to these variations, each mapping unit in the soil survey includes a range of soil properties because areas of other soils may be included within each delineated mapping unit. This is the reason for the admonition to do on-site soil evaluations for detailed site planning. Soil scientists are just beginning to document the variability of soils by quantitative descriptions of map unit compositions.

Second, corrective measures for overcoming soil limitations and their costs may be quickly outdated since the range of technological alternatives is increasing thanks to current research findings. In the present study, cost data were collected during 1978 and the soil potential ratings generated considered all current alternatives used in Eaton County, Michigan, to overcome particular soil hazards for the five non-agricultural land uses. Updating of these ratings will almost surely be required to keep up with the new innovative technologies being developed and with rising material and labor costs.

Third, the present analysis was handicapped by the absence of data concerning the costs of continuing limitations. Such data are critically important because they would provide a more precise and quantitative evaluation of a soil's potential for a given land use. Absence of such data led the researcher to develop a qualitative rating scheme for this study to help evaluate the degree of each soil's continuing limitations. Therefore, it was necessary to draw inferences about soil performance with the aid of technical experts rather than having detailed research data at hand to help make these decisions. Hence, analysis based on such assumptions may possibly be under or overestimating the severity of these continuing limitations.

Implications for Future Research

In light of the above limitations to this study, the investigator believes that the following research topics merit special attention:

1. Research Concerning Map Unit Characterization.

If soil scientists are to preserve their credibility in the eyes of soil survey users, they should document the variability and preciseness of the mapping units. What are the confidence limits of characterization data and interpretations? How much effort is needed to increase the confidence limits of soil surveys? What techniques or mechanical devices are best suited for this purpose? These appear to be key questions which merit special attention by the National Cooperative Soil Survey.

2. Research Concerning the Costs of Continuing Limitations.

This present study was unfortunately handicapped by the lack of adequate existing data, particularly on the costs of limitations remaining after corrective measures are applied to overcome particular soil hazards. In future studies in this area, effective ways and means of collecting and analyzing such data should be initiated. It is important to discover from such a study the data sources where such information may be found and the time and costs required to procure this information.

3. Research Concerning the Social, Economic, and Political Impacts of Innovative Technologies for Overcoming Soil Limitations Upon Potential Land Uses.

The introduction of new innovative technologies to overcome soil hazards invites serious questions regarding the potential impact on a region's natural resources. What is the possible impact which such systems may have on the land uses in the region? What land use controls are available and are effective? The introduction of this technology will mean that some new ways of planning and guiding land use may have to be developed. Results from this study tend to indicate that land which may have been previously closed to urban development may now be potentially available, provided that certain corrective measures are applied to overcome soil hazards. Thus, urban growth can be potentially induced in large areas of land for which development has not previously been planned. A well designed research study should be instituted to examine at this time land use regulations to determine what strategies and courses of action might best be taken.

APPENDICES

APPENDIX A

DESCRIPTIONS OF SOIL SERIES IN EATON COUNTY, MICHIGAN

APPENDIX A

DESCRIPTIONS OF SOIL SERIES IN EATON COUNTY, MICHIGAN

Adrian

Adrian soils consist of very poorly drained, nearly level, thin organic soils that formed over sand or loamy sand material. They occupy closed depressions, swamps, bogs, and broad low lying areas. Adrian soils have 16 to 50 inches of organic deposits over stratified sand and fine sand.

The Adrian soils in most landscapes are generally near the Houghton, Palms, and Edwards soils. They have a thinner organic layer than the Houghton soils, and they have coarser underlying material than the Palms soils. They differ from the Edwards soils in having sand instead of marl below the O horizons.

Bixby

Bixby soils consist of well drained, nearly level to very gently sloping soils on outwash plains. They formed in loamy material, less than 40 inches thick, over dominantly sandy materials that usually become gravelly with depth. These soils have been deeply leached.

The Bixby soils in most landscapes are near the Boyer soils. They differ from the Boyer soils in having finer textures in the B horizon and in having thicker and more acid sola. The Bixby soils are in a toposequence with the Matherton soils. They differ from the Matherton soils in lacking grayish brown colors below the Ap horizon.

Borrow Land

Borrow land consists of areas from sand and loamy soil materials have been excavated. The original soils are impossible to identify because of mechanical mixing. In most areas the textures are variable and on site investigation is needed. Usually sandy borrow land is associated with coarse or moderately coarse textured soils and loamy borrow land is associated with medium to fine textured soils.

Boyer

Boyer soils consist of well drained, nearly level to hilly soils which formed in sandy loam and loamy sand materials underlain at depth between 24 and 40 inches by calcareous gravelly very coarse sand. These soils are on outwash plains, moraines, and along old glacial drainage channels.

The Boyer soils are generally near the Bixby, Oshtemo, and Spinks soils. They differ from the Bixby soils in having coarser textured B horizons and in having thinner and less acid sola. They differ from the Oshtemo soils in having a shallower depth to the C horizon. The Boyer soils differ from the Spinks soils in having a finer textured continuous B horizon and a shallower depth to the C horizon,

Brady

Brady soils consist of somewhat poorly drained, nearly level to gently sloping soils which formed in sandy loam and loamy sand material over calcareous coarse sand. These soils are on outwash plains and along old glacial drainage channels.

The Brady soils are similar to the Bronson, Matherton, and Wasepi soils. They differ from the Bronson soils in having gray mottles in the upper part of the B horizons. They differ from the Matherton soils in having coarser textures in the B horizons and in having a greater depth to the C horizons. They differ from the Wasepi soils in having greater depth to the C horizons.

Bronson

Bronson soils consist of moderately well drained, nearly level to very gently sloping soils which formed in sandy and loamy material over calcareous coarse sand. These soils are on outwash plains and along old glacial drainage channels.

The Bronson soils are similar to the Brady, Tuscola, and Wasepi soils. They differ from the Brady soils in lacking gray mottles in the upper part of the B horizon. They differ from the Tuscola soils in having coarser textures in the B and C horizons. They differ from the Wasepi soils in having greater depths to the calcareous C horizon and in lacking grayish brown mottles in the upper part of the B horizon.

Capac

Capac soils consist of somewhat poorly drained, nearly level to gently undulating soils on till plains and low moraines. These soils formed in calcareous loamy glacial till. Capac soils have a loamy surface horizon over a loamy to clay loam subsoil. The underlying material at 30 inches is calcareous browm loam.

The Capac soils in most landscapes are near the Marlette and Metamora soils. They differ from the Marlette soils in having grayish brown mottles in the upper part of the B horizon. They differ from the Metamora soils in having finer textures in the A and B horizons.

Cohoctah

Cohoctah soils consist of poorly and very poorly drained, nearly level soils on the flood plains of streams and rivers. These soils formed in sandy and loamy materials that were deposited by flood waters. Cohoctah soils have a surface layer of fine sandy loam, 14 inches thick. Underlying the surface layer is a series of stratified layers, 27 inches thick, consisting of sandy loams, loamy sands, and loams. The underlying stratified material at 41 inches is loose mottled sand.

The Cohoctah soils are similar to the Gilford and Sloan soils. They differ from the Gilford soils in having less gravel in the profile, and an organic matter content that decreases irregularly with depth. They differ from the Sloan soils in having coarser textures in the upper C horizons. The Cohoctah soils in most landscapes are near the Houghton soils. They differ from the Houghton soils in having mineral instead of organic horizons.

Colwood

Colwood soils consist of poorly and very poorly drained, nearly level soils that are located in depressions and on broad flats of lake plains, old glacial drainage ways, and till plains. These soils formed in stratified very fine sands to silty material. Colwood soils have a surface layer of loam, 11 inches thick. Underlying the surface layer is a series of stratified layers, 22 inches thick, consisting of loams, silt loams, and light silty clay loams. The underlying material at 33 inches consists of calcareous silt loam.

The Colwood soils in most landscapes are near the Kibbie soils. The Colwood soils differ from the Kibbie soils by having more predominant gray colors in the B horizon. The Colwood soils are similar to the Parkhill and Lenawee soils. They differ from the Parkhill soils by having stratified material throughout the solum and havd coarser textured material in the C horizon. The Colwood soils differ from the Lenawee soils in having a coarser texture, and a thicker A horizon.

Edwards

Edwards soils consist of very poorly drained, nearly level, thin organic soils. The organic layers are about 35 inches thick, underlain by marl. These soils are in swamps, along waterways, and in depressions in till plains and moraines.

The O horizons of the Edwards soils in similar materials, to the Adrian, Palms, and Houghton soils. They differ from the Adrian soils by having marl instead of sand and loamy sand below the O horizons. The Edwards soils differ from the Palms soils by having marl instead of loam materials below the O horizons. They differ from the Houghton soils by having thinner organic deposits.

Gilford

Gilford soils consist of very poorly drained, nearly level soils in depressions on outwash plains and along old glacial drainage channels. These soils formed in coarse loamy material underlain by calcareous coarse sand. Gilford soils have a loamy surface layer, 11 inches thick. Underlying the surface layer is a subsoil, 20 inches thick, consisting of sandy loams. The underlying calcareous material at 33 inches is coarse sand.

The Gilford soils are similar to the Colwood and Cohoctah soils. They differ from Colwood soils in having calcareous coarse sand below the B horizon while Colwood soils have stratified layers of silt loam, and very fine sand. They differ from Cohoctah soils in having more gravel in the profile, and an organic matter content that decreases regularly with depth.

Hillsdale

Hillsdale soils consist of well drained, gently sloping to gently rolling soils of till plains and moraines. These soils formed in sandy loam material that has been deeply leached. Hillsdale soils have a sandy loam surface layer, 9 inches thick. Underlying the surface layer is a subsoil, 87 inches thick, consisting of sandy loams.

The Hillsdale soils are similar to the Marlette and Oshtemo soils. They differ from the Marlette soils in having coarser textures in the B and C horizons. They differ from the Oshtemo soils in having sandy loam instead of coarse sand in the C horizon.

Houghton

Houghton soils consist of very poorly drained, nearly level organic soils. The organic material extends to a depth greater than 50 inches. Typically, the organic materials range from 5 to 20 feet and a few deposits range to as much as 48 feet or more. These soils are in swamps, along waterways, and in depressions on the floodplains, outwash plains, till plains, and moraines.

The Houghton soils formed in similar materials, in the O horizons, as the Adrian, Edwards, and the Palms soils. They differ from the Adrian, Edwards, and Palms soils in having thicker organic deposits. The Houghton soils in most landscapes are near the Cohoctah soils. They differ from the Cohoctah soils in having organic instead of mineral horizons.

Kibbie

Kibbie soils consist of somewhat poorly drained, nearly level to very gently sloping soils on lake plains and in old glacial drainageways. These soils formed in loamy material and in water laid deposits of very fine sand, and silt. The surface layer consists of fine sandy loam, 9 inches thick. The underlying material, at 30 inches, is stratified silt loam and very fine sand with thin lenses of loamy fine sand.

The Kibbie soils in most landscapes are near the Colwood and Tuscola soils. They differ from the Colwood soils in lacking predominant gray colors in the upper B horizon. The Kibbie soils differ from the Tuscola soils in having more predominant dark grayish brown colors on the faces of peds immediately below the Ap horizon.

Lenawee

Lenawee soils consist of poorly and very poorly drained soils on lake plains and till plains modified by shallow lake waters. These soils formed in silty clay loam material containing thin lenses of silt loam, silt, and fine sand. The surface horizon consists of clay loam, 9 inches thick, which is underlain by a subsoil of mottled silty clay loam. The underlying material at 30 inches is calcareous silty clay loam with thin lenses of fine sand and very fine sand.

The Lenawee soils are similar to the Parkhill and Colwood soils. But, they are finer textured throughout the profile than the Parkhill and Colwood soils and have a thinner Ap horizon than the Colwood soils.

Marlette

Marlette soils consist of well drained and moderately well drained, nearly level to steep soils on till plains and moraines. These soils formed in calcareous loam glacial till. The surface layer, 9 inches thick, is loam. The subsoil, 29 inches thick, is clay loam. The underlying material at 38 inches is calcareous loam.

The Marlette soils in most landscapes are near the Capac and Owosso soils. They differ from the Capac soil in lacking gray mottles in the upper part of the B horizon. They differ from the Owosso soils in having finer textured A and B horizons. The Marlette soils are similar to the Hillsdale and Winnesheik soils. They differ from the Hillsdale soils in having finer textures in the B and C horizons. They differ from the Winnesheik soils by lacking limestone bedrock within 20 to 40 inches of the land surface.

Matherton

Matherton soils consist of somewhat poorly drained, nearly level to very gently sloping soils on broad outwash plains and terraces along old glacial drainage channels. These soils formed in loamy material over calcareous coarse sand and gravel.

The Matherton soils are in a toposequence with the Bixby soils. They differ from the Bixby soils in having grayish brown colors immediately below the Ap horizons. The Matherton soils are similar to the Brady, Sebewa, and Shoals soils. They differ from the Brady soils in having finer textures in the B horizons and having a shallower depth to the C horizon. They differ from the Sebewa soils in having a thinner Ap horizon, and lack the predominant gray colors in the B horizon. They differ from the Shoal soils by having an organic matter content that decreases regularly with depth.

Metamora

Metamora soils consist of somewhat poorly drained, nearly level to gently sloping soils on till plains and river terraces. These soils formed in sandy loam material underlain at 20 to 40 inches with calcareous glacial loam till.

The Metamora soils in most landscapes are near the Capac and Owosso soils. They differ from the Capac soils in having coarser textures in the A and B horizons. The Metamora soils are similar to the Owosso and Wasepi soils. They differ from the Owosso soils in having mottles in the B horizon. They differ from the Wasepi soils in having loamy materials in the C horizons.

Metea

Metea soils consist of well drained, nearly level to moderately steep soils on moraines and till plains. These soils formed in sandy glaciofluvial materials over loamy glacial till at depths of 20 to 40 inches. The surface layer, 9 inches thick, is loamy sand. The subsoil consists of three layers, 10 to 30 inches thick, of loamy sands on loams and light clay loams. The underlying material at 43 inches is calcareous loam.

The Metea soils are similar to the Owosso and Spinks soils. They differ from the Owosso soils in having coarser textures in the A and B horizons. They differ from the Spinks soils in having loamy materials below 20 to 40 inches.

Oshtemo

Oshtemo soils consist of well drained, nearly level to sloping soils on outwash plains, moraines, and old glacial drainage channels. These soils formed in sandy loam material underlain by calcareous coarse sand at depths below 40 to 60 inches.

The Oshtemo soils in most landscapes are near the Boyer and Spinks soils. They differ from the Boyer soils in having a greater depth to the C horizon. They differ from the Spinks soils in having finer texture throughout the solum. The Oshtemo soils are similar to the Hillsdale soils. They differ from the Hillsdale soils in having coarse sand instead of sandy loam in the C horizons.

Owosso

Owosso soils consist of well drained, nearly level to hilly soils on till plains and moraines. These soils formed in sandy loam material 20 to 40 inches thick over calcareous loamy till material.

The Owosso soils in most landscapes are near the Marlette soils. They differ from the Marlette soils in having coarser textures in the A and B horizons. The Owosso soils are similar to the Metamora and Metea soils. They differ from the Metamore soils in lacking mottles in the B horizon. They differ from the Metea soils in having a finer texture in the A and B horizons.

Palms

Palms soils consist of very poorly drained, nearly level or slightly depressional, thin organic soils. These soils are in swamps, along waterways, and in depressions on till plains and moraines. The organic layers are about 34 inches thick over loamy material.

The Palms soils were formed in similar materials in the O horizon, to those in the Adrian, Houghton, and Edwards soils. They differ from the Adrian soils in having loamy materials instead of sand and loamy sand below the O horizons. The Palms soils differ from the Houghton soils in having thinner organic deposits. They differ from the Edwards soils in having loamy materials instead of marl below the O horizons.

Parkhill

Parkhill soils consist of poorly and very poorly drained, nearly level soils on till plains and low moraines. These soils formed in loamy material underlain by calcareous loam glacial till. The surface layer, 9 inches thick, is loam. The subsoil, 25 inches thick, is mottled clay loam. The underlying material from 34 to 60 inches is calcareous loam.

The Parkhill soils are similar to the Colwood, Lenawee, and Sebewa soils. They differ from the Colwood soils in lacking stra

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stratified material throughout the solum and lacking coarser textured material in the C horizon. The Parkhill soils differ from the Lenawee soils in being coarser textured throughout the profile. They differ from Sebewa soils in having loamy C horizons.

Sebewa

Sebewa soils consist of poorly and very poorly drained, nearly level soils in the depressions on broad outwash plains and old glacial drainage channels. These soils formed in loamy materials over calcareous coarse sand and gravel. The surface layer, 11 inches thick, is loam. The subsoil consists of sandy clay loam, clay loam, or gravelly clay loam, 22 inches thick. The underlying material at about 36 inches is calcareous gravelly sand.

The Sebewa soils are similar to the Matherton and Parkhill soils. They differ from the Matherton soils in having a thicker Ap horizon and predominantly gray colors in the B horizon. The Sebewa soils differ from the Parkhill soils in lacking loamy C horizons.

Shoals

Shoals soils consist of somewhat poorly drained, nearly level soils that occur on flood plains. These soils formed in loamy materials deposited by flood water. The surface layer, 9 inches thick, is loam. Underlying the surface layer is a series of layers, 43 inches thick, consisting of mottled silt loams.

The underlying materials, at 52 inches, are calcareous fine and very fine sands.

The Shoals soils are similar to the Matherton and Sloan soils. They differ from the Matherton soils in having an organic matter content decreasing irregularly with depth and have finer texture substrata. They differ from the Sloan soils in lacking predominant gray colors below the A horizon and within 30 inches of the surface.

Sloan

Sloan soils consist of very poorly drained, nearly level soils on flood plains. These soils formed in loamy materials deposited by flood water. The surface layer, 11 inches thick, is loam. The subsoil, 30 inches thick, consists of stratified loams, silt loams, and sandy loams. The underlying material, at 41 inches, is calcareous coarse and very coarse sand.

The Sloan soils in most landscapes are near the Shoals soils. They differ from the Shoals soils in having predominantly gray colors below the A horizon. The Sloan soils are similar to the Cohoctah and Sebewa soils. They differ from the Cohoctah soils in having finer textures in the upper C horizons. They differ from the Sebewa soils in having organic matter that decreases irregularly with depth.

Spinks

Spinks soils consist of well drained, nearly level to hilly soils on sandy ridges on the till plains, moraines, and sandy beach ridges or along major streams. These soils formed in loamy and sandy material. The surface layer, 9 inches thick, is loamy sand. The subsoil, 32 inches thick, consists of layers of loose sand banded with thin layers of loamy sand or sandy loam. The underlying material is calcareous coarse sand at 58 inches.

The Spinks soils in most landscapes are near the Boyer and Oshtemo soils. They differ from the Boyer soils in having a coarser textured discontinuous B horizon and a greater depth to the C horizon. They differ from the Oshtemo soils in having a coarser texture throughout the solum. The Spinks soils are similar to the Metea soils. They differ from Metea soils in lacking loamy materials below 20 to 40 inches.

Tuscola

Tuscola soils consist of moderately well drained, nearly level to gently sloping soils in till plains and low moraines. These soils formed in water laid deposits of loams, very fine sand, and silt. The surface layer, 9 inches thick, in sandy loam. The subsoil consists of layers, 22 inches thick, containing silty clay loams and loams. The underlying material, at 31 inches, is calcareous stratified silt loam, very fine sand, and some fine sand.

The Tuscola soils in most landscapes are near the Kibbie soils. They differ from the Kibbie soils in lacking dark grayish brown colors on the faces of peds immediately below the Ap horizon. The Tuscola soils are similar to the Bronson soils. They differ from the Bronson soils in having finer textures in the B and C horizons.

Wasepi

Wasepi soils consist of somewhat poorly drained, nearly level and very gently sloping soils on broad outwash plains and terraces of old glacial drainage channels. These soils formed in coarse loamy material underlain by calcareous coarse and very coarse sand. The surface layer, 9 inches thick, is sandy loam. The subsoil, 28 inches thick, consists of sandy loam, sandy clay loams, and loamy sands. The underlying material at 37 inches is calcareous coarse sand and very gravelly sand.

The Wasepi soils are similar to the Brady, Bronson, Owosso, and Wasepi variant soils. They differ from the Brady and Bronson soils in being shallower to the C horizon. In addition they have grayish brown mottles in the upper part of the B horizon which the Bronson soils lack. They differ from the Owosso soils in lacking loamy materials in the C horizons. They differ from the Wasepi variant soils in lacking sandstone bedrock at depths within 20 to 40 inches.

Wasepi Variant

The Wasepi Variant soil consists of somewhat poorly drained, nearly level and very gently sloping soils on terraces. These soils formed in coarse loamy outwash materials, 20 to 40 inches thick over sandstone bedrock. The surface layer, 9 inches thick, is sandy loam. The subsoil, 17 inches thick, consists of sandy loams. The underlying material at 26 inches is sandstone bedrock.

The Wasepi variant soils are similar to the Wasepi soils. They differ from the Wasepi soils by having sandstone bedrock within depths of 20 to 40 inches.

Winneshiek

Winneshiek soils consist of well drained, nearly level and very gently sloping soils on terraces. These soils formed in loamy outwash and water laid materials 20 to 40 inches thick over limestone bedrock. The surface layer, 9 inches thick, is silt loam. The subsoil, 17 inches thick, consists of loams, clay loams, and heavy clay loams. The underlying material at 26 inches is limestone bedrock.

The Winneshiek soils are similar to the Marlette soils. They differ from the Marlette soils in having limestone bedrock within 20 to 40 inches of the land surface.

SOURCE: Feenstra, et al., Soil Survey of Eaton County, Michigan, 1978.

APPENDIX B

AVERAGE UNIT PRICES OF MATERIALS AND LABOR USED IN CORRECTIVE MEASURES FOR SELECTED LAND USES IN EATON COUNTY, MICHIGAN

Table B1. Average Unit Prices of Materials and Labor Used in Corrective Measures for On-Site Waste Disposal in Eaton County, Michigan

Materials and Labor	Cost (1978)	Unit of Measurement
Sewage tanks		
Septic tanks (1,000 gallons)	450	each
Drop box	50	each
Wet well pumping chamber[a]	230	each
Holding tank[b]	750	each
Drainfield construction		
Excavation of trench	1.50	linear foot
Crushed stone (3/4")	9.43	cubic yard
Perforated PVC pipe (4" diameter)[c]	2.88	linear foot
Layer of untreated building paper	.04	square yard
Backfill of trench	7.17	cubic yard
Sand mound construction		
Sandfill	4.85	cubic yard
Perforated PVC pipe for laterals[c]	1.87	linear foot
Crushed stone (3/4")	9.43	cubic yard
Topsoil	6.10	cubic yard

Note: Average unit costs taken from R.S. Means Company, Inc., Building Construction Cost Data (Duxbury, Massachusetts: R.S. Means Company Inc., 1978). These were adjusted for material and labor costs existing in the Lansing metropolitan area in 1978. The prices of these items in the table include adjustments for contractors' and subcontractors' overhead and profit which is estimated at 30 percent.

[a]Cost is for a single pump rated at 1/3 hp. with an electronic warning device to indicate extremely high water levels in the pumping chamber.

[b]Includes electric warning device.

[c]Includes all costs for PVC pipe fittings.

Table B2. Average Unit Prices of Materials and Labor Used in Corrective Measures for Residential Streets and Roads in Eaton County, Michigan.

Materials and Labor	Cost (1978)	Unit of Measurement
Clearing and grubbing[a]	.11	square yard
Excavation and grading		
Muck and peat excavation	4.70	cubic yard
Balanced cut and fill	2.30	cubic yard
Delivered fill	1.95	cubic yard
Prepare and roll subgrade	.34	square yard
Paving		
Bituminous wearing course[b]	21.00	ton
Bituminous base course[c]	16.00	ton
Tack or prime coat	.50	gallon

Note: Average unit costs taken from Michigan Department of State Highways and Transportation, Report #114 3rd Quarter 1978 (Lansing: Michigan Department of State Highways and Transportation, 1978). These were adjusted for material and labor costs existing in the Lansing metropolitan area in 1978. The prices of these items in the table include adjustment for contractors' and subcontractors' overhead and profit estimated at 30 percent.

[a]Roadway site assumed to be 50 percent wooded with average size trees and 50 percent old field.

[b]Michigan Department of State Highways and Transportation Specification 4.12.

[c]Michigan Department of State Highways and Transportation Specification 3.05, hot-mix asphalt base.

Table B3. Average Unit Prices of Materials and Labor Used in Corrective Measures for Residential Dwellings With Basements in Eaton County, Michigan

Materials and Labor	Cost ($1978)	Unit of Measurement
Site/Subgrade Preparation		
Clearing and grubbing[a]	.11	square yard
Cut and fill	2.30	cubic yard
Excavate peat and muck	4.70	cubic yard
Fill material	1.95	cubic yard
Basement excavation	2.30	cubic yard
Rock excacation	10.75	cubic yard
Footing		
Erect and strip forms[b]	1.20	square foot
Poured concrete footing (8" x 16")	32.00	cubic yard
Thru-footing drain openings	1.09	linear foot
Horizontal reinforcing bar (#6)	.38	linear foot
Fixed vertical, hooked dowels	.36	linear foot
Wall		
Erect and strip forms	1.70	square foot
Poured concrete wall	34.00	cubic yard
Reinforcing bars		
Horizontal bar below window (#6)	.38	linear foot
Vertical bar each side of window (#4)	.18	linear foot
Other Vertical bars (#4)	.18	linear foot
Expansion dowels with cap (3/4" x 12")	.95	each
Control joints	.10	linear foot
Floor slab		
Concrete mud slab	34.60	cubic yard
Concrete slab	34.60	cubic yard
Underslab gravel (4" thick)	1.40	square yard
Footing gravel (18" x 18")	.42	linear foot
Welded wire mesh (6 x 6-8/8)	.24	square foot
Reinforcing bars		
#4 bars	.18	linear foot
#6 bars	.38	linear foot
Control joint	.10	linear foot
Finish concrete	.15	square foot
Waterproofing (for wall or floor slab)		
Polyethylene film (6 mil)	.06	square foot
Concrete admixture	1.50	cubic yard
Crystalline penetration treatment	.39	square foot
Pre-fabricated adhesive membrane	.49	square foot

Table B3. Continued

Materials and Labor	Cost ($1978)	Unit of Measurement
Liquid applied elastometric membrane	.30	square foot
Protection boards	.14	square foot
Control joint waterproofing	.03	square foot
Outside corner protection board	.02	square foot
Sump pump system		
Pump (1/3 H.P.) incl. pipe and fittings	150.00	each
Sump pit (24" x 30")	19.00	each
Electrical wiring	24.00	each

Note: Average unit costs from R.S. Means Company, Inc., Building Construction Cost Data (Duxbury, Massachusetts: R.S. Means Company, Inc., 1978) and Coert Engelsman, 1978 Engelsman's General Construction Cost Guide (New York: Van Nostrand Reinhold Company, 1978). These were adjusted for material and labor costs existing in the Lansing metropolitan area during 1978. An additional 30 percent has been added to the estimated cost of materials and labor to cover contractors' and subcontractors' profit and overhead plus engineering fees.

[a]Dwelling site assumed to be 50 percent wooded with average size trees and 50 percent old field.

[b]Cost assumes reuse factor of 6.

Table B4. Average Unit Prices of Materials and Labor Used in Corrective Measures for Residential Dwellings Without Basements in Eaton County, Michigan

Materials and Labor	Cost ($1978)	Unit of Measurement
Site/Subgrade Preparation		
Clearing and grubbing[a]	.11	square yard
Cut and fill	2.30	cubic yard
Excavate peat and muck	4.70	cubic yard
Fill material	1.95	cubic yard
Footings and wall		
Excavate trench	2.30	cubic yard
Erect and strip forms[b]	1.20	square foot contact area
Poured concrete footing (8" x 16")	32.00	cubic yard
Poured concrete wall	34.00	cubic yard
Horizontal reinforcing bar (#6)	.38	linear foot
Footing underdrains	1.56	linear foot
Concrete slab construction		
Compact fill	2.40	square yard
Soil poisoning for termites	.18	square foot
Slab underdrains	1.56	linear foot
Underslab gravel (4" thick)	1.40	square yard
Welded wire mesh (6 x 6-8/8)	.24	square foot
Vapor barrier (6 mil)	.06	square foot
Perimeter insulation	.50	square foot
Poured concrete slab	34.60	cubic yard
Finish concrete	.15	square foot
Curing	.06	square foot
Drainage		
Subsurface drainage	1.25	linear foot

Note: Average unit costs taken from Coert Engelsman, 1978 Engelsman's General Construction Cost Guide (New York: Van Nostrand Reinhold Company, 1978), pp. 2B-1, 3-1 - 3-19. These were adjusted for material and labor costs existing in the Lansing metropolitan area during 1978. An additional 30 percent has been added to the estimated costs of materials and labor to cover contractors' and subcontractors' profit and overhead plus engineering fees.

[a]Dwelling site assumed to be 50 percent wooded with average size trees and 50 percent old field.

[b]Cost assumes reuse factor of 6.

Table B5. Average Unit Prices of Materials and Labor Used in Corrective Measures for Residential Waterlines in Eaton County, Michigan

Materials and Labor	Cost ($1978)	Unit of Measurement
Trench excavation[a]		
Common soil	2.30	cubic yard
Muck and peat	4.70	cubic yard
Rock	10.75	cubic yard
Preparation of trench for pipe installation		
Dewatering trench	3.45	cubic yard
Sand cushion	3.50	cubic yard
Delivered fill	1.95	cubic yard
Pipe installation		
Cast-iron soil pipe (8" diameter)[b]	9.20	linear foot
Trim trench for pipe bills	.65	linear foot
Polyethylene encasement (10 mil)	.64	linear foot
Backfill of trench	.75	cubic yard
Tamping backfill[c]	5.25	cubic yard

Note: Average unit costs taken from McGraw-Hill Information Systems Company, 1978 Dodge Guide to Public Works and Heavy Construction Costs (New York: McGraw-Hill Information Systems Company, 1978), pp. 18-19. These were adjusted for material and labor costs existing in the Lansing metropolitan area during 1978. An additional 30 percent has been added to the estimated costs of materials and labor to cover contractors' and subcontractors' profit and overhead plus engineering fees.

[a]Trench assumed to be 2 feet wide and 5 feet deep to accommodate 8 inch diameter pipe.

[b]Cost includes furnishing pipe, valves, fittings, and fire hydrants. The assumed distance on residential streets between hydrants is 500 feet. The average cost per hydrant is $470 or $.98 per linear foot of water line. The assumed distance between valves on residential streets is 800 feet. The average valve cost is $540 or $.72 per linear foot of water line.

[c]Hard compaction in 6 inch layers.

APPENDIX C

CORRECTIVE MEASURES AND THEIR COSTS FOR SELECTED LAND USES IN EATON COUNTY, MICHIGAN

Table C1. Corrective Measures and Their Costs for On-Site Waste Disposal in Eaton County, Michigan

Corrective Measures	Cost Per Dwelling ($1978)
Increase infield size	
0-11 minutes per inch, percolation rate	700-900[a]
11-25 minutes per inch, percolation rate	900-1200
26-45 minutes per inch, percolation rate	1200-1600
46-60 minutes per inch, percolation rate	1600-2000
Slope design	
6-12 percent slopes	50-350
12-18 percent slopes	350-550
18-25 percent slopes	550-850
Sand mound design	
0-6 percent slopes	2600-2800
6-12 percent slopes	2800-3200
Holding tank	2000-4000

Note: Costs are based on water use for a three bedroom, single-family dwelling, estimated at 75 gallons per person per day or 150 gallons per bedroom per day, with automatic washer, dishwasher, and garbage disposal unit.

[a]Range of study averages.

Table C2. Corrective Measures and Their Costs for Residential Streets and Roads in Eaton County, Michigan

Corrective Measures	Cost per Linear Foot ($1978)
Increase pavement thickness	
Excellent subgrade support	14.00-17.00[a]
Good subgrade support	17.00-22.00
Poor subgrade support	22.00-26.00
Add fill to raise grade of road	6.00-10.00
Balanced cut and fill	
6-12 percent slopes	1.00-3.00
12-18 percent slopes	3.00-6.00
18-25 percent slopes	6.00-10.00
Excavate peat and muck, replace with fill	16.00-26.00

Note: Costs are calculated for residential street sections, designed to handle a maximum of 15 trucks and 500 cars per day. The typical road section is assumed to be 30 feet wide and paved with a hot mix asphalt base and bituminous concrete wearing course.

[a]Range of study averages rounded off to whole dollar amounts.

Table C3. Corrective Measures and Their Costs for Residential Dwellings with Basements in Eaton County, Michigan

Corrective Measures	Cost per Dwelling ($1978)
Waterproof basement construction	
Conventional design	5000-5400[a]
Drained system design	6000-6800
Undrained (barge) system design	7100-9000
Cut and fill	
6-12 percent slopes	400- 700
12-18 percent slopes	600- 900
18-25 percent slopes	800-1200
Excavate rock	400- 800
Excavate peat and muck	600-1300
Add fill to raise grade	300- 600
Improve surface drainage	200- 300

Note: Costs are calculated for the foundation area of single-family dwellings of three stories or less with basements. The foundation area is assumed to be approximately 30 feet by 50 feet or 1500 square feet on a one-half acre lot. Landscaping costs are calculated for this average lot size.

[a]Range of study averages rounded off to nearest hundred dollar amounts.

Table C4. Corrective Measures and Their Costs for Residential Dwellings Without Basements in Eaton County, Michigan

Corrective Measures	Cost per Dwelling ($1978)
Reinforced slab	
Type I slab-on-grade	3000-3500[a]
Type II slab-on-grade	3500-4000
Cut and fill	
6-12 percent slopes	400- 600
12-18 percent slopes	600- 900
18-25 percent slopes	800-1200
Add fill to raise grade	300- 500
Drainage of footing and slab	200- 400
Excavate peat and muck	600-1300
Improve surface drainage	200- 300

Note: Costs are calculated for the foundation area of single-family dwellings of three stories or less without basements. The foundation area is assumed to be approximately 300 feet by 50 feet or 1500 square feet sited on a 1/3 to 1/2 acre lot Landscaping costs are calculated for this average lot size.

[a]Range of study averages rounded off to nearest hundred dollar amounts.

Table C5. Corrective Measures and Their Cost for Residential Waterlines in Eaton County, Michigan

Corrective Measures	Cost per Linear Foot[a] ($1978)
Install pipe with pipe trencher	10.00-12.50
Excavate peat and muck[b]	2.00- 2.50
Excavate bedrock[b]	3.50- 7.50
Dewater trench after excavation	1.25- 1.75
Tamp back in layers by hand	2.00- 3.00
Thrust blocking and anchoring	2.50- 3.50

Note: Costs are calculated for 8-inch diameter residential water mains buried 6 inches below greatest recorded frost penetration (60 inches) in the area.

[a]Range of study averages.

[b]Includes cost for bed of sand (6 inches thick) placed on bottom of trench.

APPENDIX D

NUMERIC CODES FOR SOILS AND NATURAL RESOURCE DATA IN WINDSOR TOWNSHIP FILE

Table D1. Numeric coding scheme for soil drainage and slope in Windsor Township

Drainage Class	Description	Numeric Code
A	Well-moderately	1
B	Somewhat poorly	2
C	Poorly-very poorly	3
Water or made land		

Slope Class	Percent	Numeric Code
A	0-2	1
B	2-6	2
C	6-12	3
D	12-18	4
E	18-25	5
F	25+	6

Source: Michigan State University, Project for the Use of Remote Sensing in Land Use Policy Formulation, "Report on the Natural Resource Information System Developed For the Tri-County Regional Planning Commission," 1976, Appendix B-2.

Table D2. Numeric Codes For Soil Management Groups in the Windsor Township

Code Number	Soil Management Group Code	Code Number	Soil Management Group Code
1	0 a	31	3/5 b
2	0 b	32	3/5 c
3	0 c	33	4/1 a
4	1 a	34	4/1 b
5	1 b	35	4/1 c
6	1 c	36	4/2 a
7	1.5 a	37	4/2 b
8	1.5 b	38	4/2 c
9	1.5 c	39	5/2 a
10	2.5 a	40	5/2 b
11	2.5 b	41	G a
12	2.5 c	42	G bc
13	3 a	43	L-2 a
14	3 b	44	L-2 c
15	3 c	45	L-4 a
16	4 a	46	L-4 c
17	4 b	47	L-M c
18	4 c	48	M c
19	5 a	49	M/1 c
20	5 b	50	M/3 c
21	5 c	51	M/4 c
22	5.3 a	52	M/ mc
23	5.7 a	53	M/R c
24	3/1 a	54	R a
25	3/.1 b	55	R bc
26	3/1 c	56	2/R a
27	3/2 a	57	2/R bc
28	3/2 b	58	3/R a
29	3/2 c	59	3/R bc
30	3/5 a	60	4/R a

Source: Michigan State University, Project for the Use of Remote Sensing in Land Use Policy Formulation, "Report on the Natural Resource Information System Developed For the Tri-County Regional Planning Commission," 1976, Appendix B-1.

Table D3. Numeric Coding Scheme for Land Cover/Use in Windsor Township File

Code Number	Land Cover/use Code	Category
1	11	Residential
2	12	Commercial, Services, Institutional
3	13	Industrial
4	14	Transportation, Communication, and Utilities
5	14A	Solid Waste Disposal
6	14B	Sewage Treatment
7	17	Extractive
8	19	Other Urban
9	2A	Cultivated Cropland and Hay
10	2B	Tree Fruits
11	2C	Brush Fruits
12	2D	Confined Feeding
13	31	Permanent Pasture
14	32	Brushlands
15	41	Broadleafed Forest
16	42	Coniferous Forest
17	43	Mixed Forest
18	5	Open Water
19	6A	Forested Wetlands
20	6B	Shrub Swamp
21	6C	Marsh

Source: Michigan State University, Project for the Use of Remote Sensing in Land Use Policy Formulation, "Report on the Natural Resource Information System Developed For the Tri-County Regional Planning Commission," 1976, Appendix C.

APPENDIX E

WINDSOR TOWNSHIP MASTER
FILE STRUCTURE

Table E1. Windsor Township Master-File Structure

Column	Item	Format
1		
2-3	County code (Eaton = 23)	I2
4-5	Township code (Windsor = 08)	I2
6-7	Row coordinate	I2
8-9	Column coordinate	I2
10	Blank	-
11-16	Interim soil map codes	A6
17	Blank	-
18-20	Land use/cover code	I3
21-23	Elevation	I3
24	Blank	-
25-26	Distance to water bodies	I2
27	Blank	-
28-33	SMG code	A6
34-35	SMG number	I2
36	Blank	-
37	Slope number	I1
38	Blank	-
39-40	Land use/cover code number	I2
41	Blank	-
42-46	Erosion (T/A/Y)	F5.1
47	Blank	-
48	Erosion class number	I1
49	Blank	-
50-52	Depth to bedrock	I3
53-55	Percent clay	I3
56	Blank	-
57	Soil drainage number	I1
58	Blank	-
59	Recharge class number	I1
60-62	Recharge scale index	I3
63	Blank	-
64-73	Land use/cover title	A10
74-76	Blank	-
77-81	Manuscript soil map code	A4
82	Blank	-
83-84	Manuscript soil map code number	I2
85	Blank	-
86	Hydrologic soil group number	I1
87-92	Design cost, waste disposal	F6.0
93	Continuing limitation, waste disposal	I1
94-95	Soil potential index number	I2
96	Soil potential class number	I1
97-102	Design cost, streets and roads	F6.0
103	Continuing limitations, streets and roads	I1

Table E1. Continued

Column	Item	Format
104-105	Soil potential index number	I2
106	Soil potential class number	I1
107-112	Design cost, foundation on grade	F6.0
113	Continuing limitations, foundation on grade	I1
114-115	Soil potential index number	I2
116	Soil potential class number	I1
117-122	Design cost, foundation below grade	F6.0
123	Continuing limitation, foundation below grade	I1
124-125	Soil potential index number	I2
126	Soil potential class number	I1
127-132	Design cost, water lines	F6.0
133	Continuing limitation, water lines	I1
134-135	Soil potential class number	I1
136	Blank	-

APPENDIX F

SOIL POTENTIAL RATINGS, RECOMMENDED DESIGNS TO OVERCOME LIMITATIONS OF SOILS FOR SELECTED LAND USES IN EATON COUNTY, MICHIGAN

Table F1. Soil potential ratings, recommended designs to overcome soil limitations, and continuing limitations of soils for on-site waste disposal in Eaton County, Michigan

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Adrian muck	Severe: Wetness, flooding	Poor: Holding tank	Severe: Cost of hauling sewage high, continual monitoring of liquid level in tank, water use restrictions.
Bixby loam, 0 to 3 percent slopes	Slight:	Excellent: Conventional septic tank filter field, small field	Slight: Possible pollution of shallow ground water supplies by effluent.
Borrow land Properties too variable to be interpreted, on-site inspection needed			
Boyer loamy sand, 0 to 6 percent slopes	Slight:	Excellent: Conventional septic tank filter field, small field	Slight: Possible pollution of shallow ground water supplies by effluent.

Table F1. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Boyer loamy sand, 6 to 12 percent slopes	Moderate: Slope	Excellent: Conventional septic tank filter field, small field, serial distribution	Slight: Possible pollution of shallow ground water supplies by effluent.
Boyer sandy loams, 0 to 6 percent slopes	Slight:	Excellent: Conventional septic tank filter field, small field	Slight: Possible pollution of shallow ground water supplies by effluent.
Boyer sandy loams, 6 to 12 percent slopes	Moderate: Slope	Excellent: Conventional septic tank filter field, small field, serial distribution	Slight: Possible pollution of shallow ground water supplies by effluent.
Boyer-Spinks loamy sands, 12 to 18 percent slopes For Spinks part see Spinks series	Severe: Slope	Good: Conventional septic tank filter field, small field, serial distribution	Moderate: Possible pollution of shallow ground water supplies by effluent, occasional surfacing of effluent downslope.

Table F1. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Brady-Bronson sandy loam, 0 to 3 percent slopes For Bronson part see Bronson series	Severe: Wetness	Fair: Septic/mound system for soils with high water table	Moderate: Maintenance of pump system, possibility of failure, power costs.
Bronson series Mapped only in a complex with Brady soils	Moderate: Wetness	Good: Conventional septic tank filter field, small field, areawide subsurface drainage	Slight: Maintenance of drainage system
Capac loam, 0 to 3 percent slopes	Severe: Wetness, percs slowly	Poor: Holding tank	Severe: Cost of hauling sewage high, continual monitoring of liquid level in tank, water use restriction.
Capac-Marlette loam, 1 to 6 percent slopes For Marlette part see Marlette series	Severe: Wetness, percs slowly	Poor: Holding tank	Severe: Cost of hauling sewage high, continual monitoring of liquid level in tank, water use restriction.

Table F1. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Cohoctah fine sandy loam, frequently flooded	Severe: Wetness, floods	Poor: Holding tank	Severe: Cost of hauling sewage high, continual monitoring of liquid level in tank, water use restrictions
Colwood loam Colwood loam, depressional	Severe: Wetness, floods	Poor: Holding tank	Severe: Cost of hauling sewage high, continual monitoring of liquid level in tank, water use restrictions
Edward muck	Severe: Wetness, floods	Poor: Holding tank	Severe: Cost of hauling sewage high, continual monitoring of liquid level in tank, water use restrictions
Gilford sandy loam	Severe: Wetness, floods	Poor: Holding tank	Severe: Cost of hauling sewage high, continual monitoring of liquid level in tank, water use restrictions
Hillsdale sandy loam 2 to 6 percent slopes	Slight:	Excellent: Conventional septic tank filter field, medium field	Slight: Possible pollution of shallow ground water supplies by effluent

Table Fl. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Hillsdale sandy loam 6 to 12 percent slopes	Moderate: Slope	Good: Conventional septic tank filter field, medium field, serial distribution	Slight: Possible pollution of shallow ground water supplies by effluent.
Houghton muck	Severe: Wetness, floods	Poor: Holding tank	Severe: Cost of hauling sewage high, continual monitoring of liquid level in tank, water use restrictions
Kibbie fine sandy loam, 0 to 3 percent slopes	Severe: Wetness, perc slowly	Fair: Septic/mound system for slowly permeable soils with high water tables	Moderate: Maintenance of pump system, possibility of failure, power costs.
Lenawee silty clay loam, depressional	Severe: Wetness, percs slowly	Poor: Holding tank	Severe: Cost of hauling sewage high, continual monitoring of liquid level in tank, water use restrictions.

Table F1. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Marlette loam, 2 to 6 percent slopes	Moderate: Percs slowly	Good: Conventional septic tank filter field, large field	Slight:
Marlette loam, 6 to 12 percent slopes Marlette clay loam, 6 to 12 percent, severely eroded	Moderate: Percs slowly, slope	Good: Conventional septic tank filter field, large field, serial distribution	Slight:
Marlette loam, 12 to 18 percent slopes	Severe: Slope	Fair: Conventional septic tank filter field, large field, serial distribution	Moderate: Occasional surfacing of effluent downslope.
Marlette loam, 18 to 25 percent slopes	Severe: Slope	Fair: Conventional septic tank filter field, large field, specially designed for improved serial distribution	Severe: Occasional surfacing of effluent downslope, maintain vegetative cover to prevent erosion.

Table F1. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Matherton loam, 0 to 3 percent slopes	Severe: Wetness	Fair: Septic/mound system for permeable soils with high water tables	Moderate: Maintenance of pump system, possibility of failure, power costs.
Metamora-Capac sandy loams, 0 to 4 percent slopes For Capac part see Capac series	Severe: Wetness	Fair: Septic/mound system for permeable soils with high water tables	Moderate: Maintenance of pump system, possibility of failure, power costs.
Metea series Mapped only in complex with Spinks soils			
Metea part of Spinks-Metea loamy sands, 0 to 6 percent slopes	Moderate: Percs slowly	Good: Conventional septic tank filter field, large field	Slight:
Metea part of Spinks-Metea loamy sands, 6 to 12 percent slopes	Moderate: Percs slowly, slope	Good: Conventional septic tank filter field, large field, serial distribution	Slight:

Table F1. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Oshtemo sandy loam, 0 to 6 percent slopes	Slight:	Excellent: Conventional septic tank filter field, small field	Slight: Possible pollution of shallow ground water supplies by effluent.
Oshtemo sandy loam, 6 to 12 percent slopes	Moderate: Slope	Excellent: Conventional septic tank filter field, small field, serial distribution	Slight: Possible pollution of shallow ground water supplies by effluent.
Owosso-Marlette sandy loam, 1 to 6 percent slopes For Marlette part see Marlette series	Moderate: Percs slowly	Good: Conventional septic tank filter field, large field, serial distribution	Slight:
Owosso-Marlette sandy loam, 6 to 12 percent slopes For Marlette part see Marlette series	Moderate: Percs slowly, slope	Good: Conventional septic tank filter field, large field, serial distribution	Slight:

Table F1. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Owosso-Marlette sandy loams, 12 to 18 percent slopes For Marlette part see Marlette series	Severe: Slope	Fair: Conventional septic tank filter field, large field, serial distribution	Moderate: Occasional surfacing of effluent downslope.
Palms muck	Severe: Wetness, flooding	Poor: Holding tank	Severe: Cost of hauling sewage high, continual monitoring of liquid level in tank, water use restriction.
Parkhill loam	Severe: Wetness, flooding	Poor: Holding tank	Severe: Cost of hauling sewage high, continual monitoring of liquid level in tank, water use restriction.
Sebewa loam	Severe: Wetness, flooding	Poor: Holding tank	Severe: Cost of hauling sewage high, continual monitoring of liquid level in tank, water use restriction.

Table F1. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Shoals-Sloan loams For Sloan part see Sloan series	Severe: Wetness, flooding	Poor: Holding tank	Severe: Cost of hauling sewage high, continual monitoring of liquid level in tank, water use restriction.
Sloan series Mapped only in a complex with Shoals soils	Severe: Wetness, flooding	Poor: Holding tank	Severe: Cost of hauling sewage high, continual monitoring of liquid level in tank, water use restriction.
Spinks loamy sand, 0 to 6 percent slopes Spinks-Metea loamy sands, 0 to 6 percent slopes For Metea part see Metea series	Slight:	Excellent: Conventional septic tank filter field, small field	Slight: Possible pollution of shallow ground water supplies by effluent.
Spinks loamy sand, 6 to 12 percent slopes Spinks-Metea loamy sands, 6 to 12 percent slopes For Metea part see Metea series	Moderate: Slope	Excellent: Conventional septic tank filter field, small field, serial distribution	Slight: Possible pollution of shallow ground water supplies by effluent.

Table F1. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Spinks part of Boyer-Spinks loamy sands, 12 to 18 percent slopes	Severe: Slope	Fair: Conventional septic tank filter field, small field, serial distribution	Moderate: Possible pollution of shallow ground water supplies by effluent, occasional surfacing of effluent downslope.
Tuscola fine sandy loam, 0 to 4 percent slopes	Severe: Wetness	Fair: Septic/mound system for soils with high water table	Moderate: Maintenance of pump system, possibility of failure, power costs.
Wasepi sandy loam, 0 to 3 percent slopes	Severe: Wetness	Fair: Septic/mound system for soils with high water table	Moderate: Maintenance of pump system, possibility of failure, power costs.
Wasepi sandy loam, bedrock variant, 0 to 3 percent slopes	Severe: Wetness, depth to bedrock	Fair: Septic/mound system for soils shallow to bedrock	Moderate: Maintenance of pump system, possibility of failure, power costs.
Winneshiek silt loam, 0 to 3 percent slopes	Severe: Depth to bedrock	Fair: Septic/mound system for soil shallow to bedrock	Moderate: Maintenance of pump system, possibility of failure, power costs.

Table F2. - Soil potential ratings, recommended design to overcome soil limitations, and continuing limitations of soils for residential roads and streets in Eaton County, Michigan

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Adrian muck	Severe: Wetness, unstable organic material, frost action	Poor: Excavate peat and muck add fill to raise grade normal thickness of full-depth pavement	Severe: Subject to frequent flooding restricting accessibility
Bixby loam, 0 to 3 percent slopes	Moderate: Frost action	Excellent: Normal thickness of full-depth pavement	Slight:
Borrow land Properties too variable to be interpreted, on-site inspection needed.			
Boyer loamy sand, 0 to 6 percent slopes	Moderate: Frost action	Excellent: Normal thickness to full-depth pavement	Slight:

Table F2. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Boyer loamy sand, 6 to 12 percent slopes	Moderate: Slope, frost action	Excellent: Cuts and fills normal thickness of full-depth pavement	Slight: Erosion control on right-of-way
Boyer sandy loams, 0 to 6 percent slopes	Moderate Frost action	Excellent: Normal thickness of full-depth pavement	Slight:
Boyer sandy loams, 6 to 12 percent slopes	Moderate: Slope, frost action	Excellent: Normal thickness of full-depth pavement	Slight: Erosion control on right-of-way
Boyer-Spinks loamy sands, 12 to 18 percent slopes For Spinks part see Spinks series	Severe: Slope	Good: Cuts and fills normal thickness of full-depth pavement	Moderate: Erosion control on right-of-way
Brady-Bronson sandy loam, 0 to 3 percent slopes For Bronson part see Bronson series	Severe: Frost action	Good: Increase thickness of full-depth pavement	Slight:

Table F2. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Bronson series Mapped only in a complex with Brady soils	Severe: Frost action	Excellent: Normal thickness of full-depth pavement	Slight:
Capac loam, 0 to 3 percent slopes	Severe: Frost action; low strength	Fair: Increase thickness of full-depth pavement	Slight:
Capac-Marlette loam, 1 to 6 percent slopes For Marlette part see Marlette series	Severe: Frost action; low strength	Fair: Increase thickness of full-depth pavement	Slight:
Cohoctah fine sandy loam, frequently flooded	Severe: Floods, frost action, low strength	Fair: Add fill to raise grade, normal thickness of full-depth pavement	Severe: Subject to frequent flooding restricting accessibilities
Colwood loam, Colwood loam, depressional	Severe: Wetness, frost action, low strength	Fair: Add fill to raise grade normal thickness of full-depth pavement	Moderate: Accessibility briefly restricted due to flooding or stream overflow

Table F2. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Edwards muck	Severe: Wetness, unstable organic material, frost action	Poor: Excavate peat and muck, add fill to raise grade, normal thickness of full-depth pavement	Severe: Subject to frequent flooding restricting accessibility
Gilford sandy loam	Severe: Wetness, frost action	Fair: Add fill to raise grade, normal thickness of full-depth pavement	Moderate: Accessibility briefly restricted due to flooding or stream overflow
Hillsdale sandy loam, 2 to 6 percent slopes	Moderate: Frost action	Excellent: Normal thickness of full-depth pavement	Slight:
Hillsdale sandy loam 6 to 12 percent slopes	Moderate: Frost action	Excellent: Cuts and fills, normal thickness of full-depth pavement	Slight: Erosion control on right-of-way

Table F2. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Houghton muck	Severe: Unstable organic material, frost action, wetness	Poor: Excavate peat and muck,add fill to raise grade, normal thickness of full-depth pavement	Severe: Subject to frequent flooding restricting accessibility
Kibbie fine sandy loam, 0 to 3 percent slopes	Severe: Frost action, low strength	Fair: Increase thickness of full-depth pavement	Slight:
Lenawee silty clay loam, depressional	Severe: Wetness, frost action	Fair: Add fill to raise grade, normal thickness of full-depth pavement	Moderate: Accessibility briefly restricted due to flooding or stream overflow.
Marlette loam, 2 to 6 percent slopes	Moderate: Frost action	Good: Increase thickness of full-depth pavement	Slight:

Table F2. - Continued

Soil Mapping Unit	Limitations and Restriction	Soil Potential and Corrective Measures	Continuing Limitations
Marlette loam, 6 to 12 percent slopes Marlette clay loam, 6 to 12 percent, severely eroded	Moderate: Frost action, slope	Good: Cuts and fill, increase thickness of full depth pavement	Slight: Erosion control on right-of-way
Marlette loam, 12 to 18 percent slopes	Severe: Slope	Fair: Cuts and fill, increase thickness of full-depth pavement	Moderate: Erosion control of right-of-way
Marlette loam, 18 to 25 percent slopes	Severe: Slope	Poor: Cuts and fill, increase thickness of full-depth pavement	Severe: Erosion control on right-of-way
Matherton loam, 0 to 3 percent slopes	Severe: Frost action	Good: Increase thickness of full-depth pavement	Slight:
Metamora-Capac sandy loams, 0 to 4 percent slopes For Capac part see Capac series	Severe: Frost action	Fair: Increase thickness of full-depth pavement	Slight:

Table F2. - Continued

Soil Mapping Unit	Limitations and Restriction	Soil Potential and Corrective Measures	Continuing Limitations
Metea series Mapped only in complex with Spinks soils			
Metea part of Spinks-Metea loamy sands, 0 to 6 percent slopes	Moderate: Frost action	Good: Increase thickness of full-depth pavement	Slight:
Metea part of Spinks-Metea loamy sands, 6 to 12 percent slopes	Moderate: Frost action, slope	Good: Cuts and fills, increase thickness of full-depth pavement	Slight:
Oshtemo sandy loam, 0 to 6 percent slopes	Slight:	Excellent: Normal thickness of full-depth pavement	Slight:
Oshtemo sandy loam, 6 to 12 percent slopes	Moderate: Slope, frost action	Excellent: Cuts and fills, normal thickness of full-depth pavement	Slight: Erosion control on right-of-way

Table F2. - Continued

Soil Mapping Unit	Limitations and Restriction	Soil Potential and Corrective Measures	Continuing Limitations
Owosso-Marlette sandy loams, 1 to 6 percent slopes For Marlette part see Marlette series	Moderate: Frost action	Good: Increase thickness of full-depth pavement	Slight:
Owosso-Marlette sandy loam, 6 to 12 percent slopes For Marlette part see Marlette series	Moderate: Slope, frost action	Good: Cuts and fills, increase thickness of full-depth pavement	Slight: Erosion control on right-of-way
Owosso-Marlette sandy loams, 12 to 18 percent slopes For Marlette part see Marlette series	Severe: Slope	Fair: Cuts and fills, increase thickness of full-depth pavement	Moderate: Erosion control on right-of-way
Palms muck	Severe: Wetness, unstable organic matter, frost action	Poor: Excavate peat and muck, add fill to raise grade, normal thickness of full depth pavement	Severe: Subject to frequent flooding restricting accessibility

Table F2. - Continued

Soil Mapping Unit	Limitations and Restriction	Soil Potential and Corrective Measures	Continuing Limitations
Parkhill loam	Severe: Wetness, frost action, floods	Fair: Add fill to raise grade, normal thickness of full-depth pavement	Moderate: Accessibility briefly restricted due to flooding or stream overflow
Sebewa loam	Severe: Wetness, frost action	Fair: Add fill to raise grade, normal thickness of full-depth pavement	Moderate: Accessibility briefly restricted due to flooding or stream overflow
Shoals-Sloam loams, For Sloan part see Sloan series	Severe: Wetness, frost action, floods	Fair: Add fill to raise grade, normal thickness of full-depth pavement	Severe: Subject to frequent flooding restricting accessibility
Sloan series, Mapped only in complex with Shoals soils	Severe: Wetness, frost action, floods	Fair: Add fill to raise grade, normal thickness of full-depth pavement	Severe: Subject to frequent flooding restricting accessibility

Table F2. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Spinks loamy sand, 0 to 6 percent slopes Spinks-Metea loamy sands, 0 to 6 percent slopes For Metea part see Metea series	Slight:	Excellent: Normal thickness of full-depth pavement	Slight:
Spinks loamy sand, 6 to 12 percent slopes Spinks-Metea loamy sands, 6 to 12 percent slopes For Metea part see Metea series	Moderate: Slope	Good: Cuts and fills, normal thickness of full-depth pavement	Slight:
Spinks part of Boyer-Spinks loamy sands, 12 to 18 percent slopes	Severe: Slope	Good: Cuts and fills, normal thickness of full-depth pavement	Moderate: Erosion control on right-of-way
Tuscola fine sandy loam, 0 to 4 percent slopes	Severe: Frost action	Fair: Increase thickness of full-depth pavement	Slight:

Table F2. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Wasepi sandy loam, 0 to 3 percent slopes	Severe: Frost action	Good: Increase thickness of full-depth pavement	Slight:
Wasepi sandy loam, bedrock variant, 0 to 3 percent slopes	Severe: Frost action, depth to bedrock	Good: Increase thickness of full-depth pavement	Slight:
Winneshiek silt loam, 0 to 3 percent slopes	Moderate: Depth to bedrock, frost action	Good: Increase thickness of full-depth pavement	Slight:

Table F3. - Soil potential ratings, recommended designs to overcome soil limitations, and continuing limitations of soils for residential dwellings with basements in Eaton County, Michigan

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Adrian muck	Severe: Wetness, unstable organic material, floods	Poor: Excavate peat and muck, raise grade of building site with fill, alternative undrained basement construction design, improve drainage control	Severe: Flooding restricting accessibility and yard use, maintenance of drainage system
Bixby loam, 0 to 3 percent slopes	Slight:	Excellent: Conventional basement construction design	Slight:
Borrow land Properties too variable to be interpreted, on-site investigation needed			
Boyer loamy sand, 0 to 6 percent slopes	Slight:	Excellent: Conventional basement construction design	Slight:

Table F3. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Boyer loamy sand, 6 to 12 percent slopes	Moderate: Slope	Excellent: Cuts and fills, conventional basement construction design	Slight: Erosion and drainage control
Boyer sandy loam, 0 to 6 percent slopes	Slight:	Excellent: Conventional basement construction design	Slight:
Boyer sandy loam, 6 to 12 percent slopes	Moderate: Slope	Excellent: Cuts and fills, conventional basement construction design	Slight: Erosion and drainage control
Boyer-Spinks loamy sands, 12 to 18 percent slopes For Spinks part see Spinks series	Severe: Slope	Good: Cuts and fills, conventional basement construction design	Moderate: Erosion and drainage control

Table F3. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Measures
Brady-Bronson sandy loams, 0 to 3 percent slopes For Bronson part see Bronson series	Severe: Wetness	Good: Alternative drained basement construction, improve drainage control	Slight: Maintenance of sump pump system and drainage system
Bronson series Mapped only in complex with Brady soils	Moderate: Wetness	Good: Alternative drained basement construction	Slight: Maintenance of sump pump system and drainage system
Capac loam, 0 to 3 percent slopes	Severe: Wetness	Good: Alternative drained basement construction, improve drainage control	Slight: Maintenance of sump pump system and drainage system
Capac-Marlette loams, 1 to 3 percent slopes For Marlette part see Marlette series	Severe: Wetness	Good: Alternative drained basement construction, improve drainage control	Slight: Maintenance of sump pump system and drainage system

Table F3. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Cohoctah fine sandy loam, frequently flooded	Severe: Floods, wetness, frost action	Poor: Raise grade of building site with fill, alternative undrained construction design, improve drainage control	Severe: Flooding restricting accessibility and yard use, maintenance of drainage system
Colwood loam Colwood loam, depressional	Severe: Wetness, floods, low strength	Fair: Raise grade of building site with fill, alternative undrained basement construction design, improve drainage control	Moderate: Flooding restricting accessibility of yard, maintenance of drainage system
Edwards muck	Severe: Wetness, floods, low strength	Poor: Excavate peat and muck, raise grade of building site with fill, alternative undrained basement construction design, improve drainage control	Severe: Flooding restricting accessibility and yard use, maintenance of drainage system

Table F3. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Gilford sandy loam	Severe: Wetness	Fair: Raise grade of building site with fill, alternative undrained basement, improve drainage control	Moderate: Flooding restricting accessibility and yard use, maintenance of drainage system
Hillsdale sandy loam, 2 to 6 percent slopes	Slight:	Excellent: Conventional basement construction design	Slight:
Hillsdale sandy loam, 6 to 12 percent slopes	Moderate: Slope	Excellent: Cuts and fills, conventional basement construction design	Slight: Erosion and drainage control
Houghton muck	Severe: Wetness, floods, low strength	Poor: Excavate peat and muck, raise grade of building site with fill, alternative undrained basement construction design, improve drainage control	Severe: Flooding restricting accessibility and yard use, maintenance of drainage system

Table F3., - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Kibbie fine sandy loam, 0 to 3 percent slopes	Severe: Wetness, low strength	Good: Alternative drained basement construction design, improve drainage control	Slight: Maintenance of sump pump system and drainage system
Lenawee silty clay loam, depressional	Severe: Wetness, floods	Fair: Raise grade of building site, alternative undrained systen, improve drainage	Moderate: Flooding restricting accessibility and yard use, maintenance of drainage system
Marlette loam, 2 to 6 percent slopes	Slight:	Excellent: Conventional basement construction design	Slight:
Marlette loam, 6 to 12 percent slopes Marlette clay loam, 6 to 12 severly eroded	Moderate: Slope	Excellent: Cuts and fills, conventional basement construction design	Slight: Erosion and drainage control

Table F3. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Marlette loam, 12 to 18 percent slopes	Severe: Slope	Good: Cuts and fills, conventional basement construction design	Moderate: Erosion and drainage control
Marlette Loam, 18 to 25 percent slopes	Severe: Slope	Fair: Cuts and fills, conventional basement construction design	Moderate: Erosion and drainage control
Matherton loam, 0 to 3 percent slopes	Severe: Wetness	Good: Alternative drained basement construction, improve drainage control	Slight: Maintenance of sump pump system and drainage system
Metamora-Capac sandy loams, 0 to 4 percent slopes For Capac part see	Severe: Wetness	Good: Alternative drained basement construction, improve drainage control	Slight: Maintenance of sump pump system and drainage system
Metea series Mapped only in complex with Spinks soils			

Table F3. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Metea part of Spinks-Metea loamy sands, 0 to 6 percent slopes	Slight:	Excellent: Conventional basement construction design	Slight:
Metea part of Spinks-Metea loamy sands, 6 to 12 percent slopes	Moderate: Slope	Excellent: Cuts and fills, conventional basement construction design	Slight: Erosion and drainage control
Oshtemo sandy loam, 0 to 6 percent slopes	Slight:	Excellent: Conventional basement construction design	Slight:
Oshtemo sandy loam, 6 to 12 percent slopes	Moderate: Slope	Excellent: Cuts and fills, conventional basement construction design	Slight: Erosion and drainage control

Table F3. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Owosso-Marlette sandy loams, 1 to 6 percent slopes For Marlette part see Marlette series	Slight:	Excellent: Conventional basement construction design	Slight:
Owosso-Marlette sandy loams, 6 to 12 percent slopes For Marlette part see Marlette series	Moderate: Slope	Excellent: Cuts and fills, conventional basement construction design	Slight: Erosion and drainage control
Owosso-Marlette sandy loams, 12 to 18 percent slopes For Marlette part see Marlette series	Severe: Slope	Good: Cuts and fills, conventional basement construction design	Moderate: Erosion and drainage control
Palms muck	Severe: Wetness, floods, low strength	Poor: Excavate peat and muck, raise grade of building site with fill, alternative undrained basement construction design, improve drainage control	Severe: Flooding restricting accessibility and yard use, maintenance of drainage system

Table F3. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Parkhill loam	Severe: Wetness, floods	Fair: Raise grade of building site with fill, alternative undrained basement construction design, improve drainage control	Moderate: Flooding restricting accessibility and yard use, maintenance of drainage system
Sebewa loam	Severe: Wetness, floods	Fair: Raise grade of building site with fill, alternative undrained basement construction design, improve drainage control	Moderate: Flooding restricting accessibility and yard use, maintenance of drainage system
Shoals-Sloan loams, For Sloan part see Sloan series	Severe: Wetness, floods	Poor: Raise grade of building site with fill, alternative undrained basement construction design, improve drainage control	Severe: Flooding restricting accessibility and yard use, maintenance of drainage system

Table F3. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Sloan series Mapped only in a complex with Shoals series	Severe: Wetness, floods	Poor: Raise grade of building site with fill, alternative undrained basement construction design, improve drainage control	Severe: Flooding restricting accessibility and yard use, maintenance of drainage system
Spinks loamy sand, 0 to 6 percent slopes Spinks-Metea loamy sands, 0 to 6 percent slopes For Metea part see Metea series	Slight:	Excellent: Conventional basement construction design	Slight:
Spinks loamy sand, 6 to 12 percent slopes Spinks-Metea loamy sands, 6 to 12 percent slopes For Metea part see Metea series	Moderate: Slope	Excellent: Cuts and fills, conventional basement construction design	Slight: Erosion and drainage control

Table F3. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Spinks part of Boyer-Spinks loamy sands, 12 to 18 percent slopes	Severe: Slope	Good: Cuts and fills, conventional basement construction design	Moderate: Erosion and drainage control
Tuscola fine sandy loam, 0 to 4 percent slopes	Severe: Wetness, low strength	Good: Alternative drained basement construction design, improve drainage control	Slight: Maintenance of sump pump system and drainage system
Wasepi sandy loam, 0 to 3 percent slopes	Severe: Wetness	Good: Alternative drained basement construction design, improve drainage control	Slight: Maintenance of sump pump system and drainage system
Wasepi sandy loam, bedrock variant, 0 to 3 percent slopes	Severe: Depth to bedrock, wetness	Fair: Excavate bedrock, alternative drained basement construction design, control	Slight: Maintenance of sump pump system and drainage system

Table F3. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Winneshick silt loam, 0 to 3 percent slopes	Severe: Depth to bedrock	Fair: Excavate bedrock, alternative drained basement construction design, improve drainage control	Slight: Maintenance of sump pump system and drainage system

Table F4. Soil potential ratings, recommended designs to overcome soil limitations, and continuing limitations of soils for residential dwellings without basements in Eaton County, Michigan

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Adrian muck	Severe: Wetness, low strength, floods	Poor: Excavate peat and muck, raise grade of building site, reinforce slab, type II slab on grade, improve drainage control	Severe: Flooding restricting accessibility and yard use, maintenance of drainage system
Bixby loam, 0 to 3 percent slope	Moderate: Frost actions, shrink-swell	Good: Reinforce slab, grade	Slight:
Borrow land Properties too variable to be interpreted, on-site investigation needed			
Boyer loamy sand, 0 to 6 percent slopes	Moderate: Frost action	Excellent: Type I slab on grade	Slight:
Boyer loamy sand, 6 to 12 percent slopes	Moderate: Slope, frost action	Good: Cuts and fills, reinforce slab, type I on grade	Slight: Erosion and drainage control

Table F4. - Continued

Soil Maping Unit	Limitations and Restrictions	Soil Potential and Conective Measures	Continuing Limitations
Boyer sandy loam, 0 to 6 percent slopes	Moderate: Frost action	Excellent: Type II slab on grade	Slight:
Boyer sandy loam, 6 to 12 percent slopes	Moderate: Frost action, slope	Good: Cuts and fills, reinforce slab, type II slab on grade	Slight: Erosion and drainage control
Boyer-Spinks loamy sands, 12 to 18 percent slopes For Spinks part see Spinks series	Severe: Slope	Fair: Cuts and fills, reinforce slab, type II slab on grade	Moderate: Erosion and drainage control
Brady-Bronson sandy loams, 0 to 3 percent slopes For Bronson part see Bronson series	Severe: Wetness, frost action	Fair: Drainage of footing and slab, reinforce slab, type II slab on grade, improve drainage control	Moderate: Maintenance of drainage systems
Bronson series Mapped only in complex with Brady soils	Severe: Frost action	Good: Reinforce slab type II slab on grade	Slight:

Table F4. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Conective Measures	Continuing Limitations
Capac loam, 0 to 3 percent slopes	Severe: Frost action, wetness	Fair: Drainage of footing and slab, reinforce slab, type II slab on grade, improve drainage control	Moderate: Maintenance of drainage systems
Capac-Marlette loams, 1 to 3 percent slopes For Marlette part see Marlette series	Severe Frost action, wetness	Fair: Drainage of footing and slab reinforce slab type II on grade, improve drainage control	Moderate: Maintenance of drainage systems
Cohoctah fine sandy loam, frequently flooded	Severe: Wetness, frost action, floods	Poor: Raise grade a building site with fill, drainage of footing, reinforce slab, type II slab on grade, improve drainage control	Severe: Flooding restricting accessibility and yard use, maintenance of drainage system

Table F4. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Colwood loam Colwood loam, depressional	Severe: Wetness, frost action	Fair: Raise grade of building site, drainage of footing and slab, reinforce slab, Type II slab on grade, improve drainage control	Moderate: Flooding restricting accessibility and yard use, maintenance of drainage system
Edwards muck	Severe: Wetness, low strength floods	Poor: Excavate peat and muck, raise grade of building site, reinforced slab, Type II slab on grade, improve drainage control	Severe: Flooding restricting accessibility and yard use, maintenance of drainage system
Gilford sandy loam	Severe: Wetness, frost action	Fair: Raise grade of building site, reinforce slab, Type II slab on grade, improve drainage control	Moderate: Flooding restricting yard use, maintenance of drainage system

Table F4. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Hillsdale sandy loam, 2 to 6 percent slopes	Moderate: Frost action	Excellent: Type II slab on grade	Slight:
Hillsdale sandy loam, 6 to 12 percent slopes	Moderate: Frost action, slope	Good: Cuts and fills, Type I slab on grade	Slight
Houghton muck	Severe: Wetness, low strength, floods	Poor: Excavate peat and muck, raise grade of building site, reinforce slab, Type II slab on grade, improve drainage control	Severe: Flooding restricting accessibility and yard use, maintenance of drainage system
Kibbie fine sandy loam 0 to 3 percent slopes	Severe: Wetness, frost action, low strength	Fair: Drainage of footing and slab, rein-forced slab, type II slab on grade, im-prove drainage control	Slight: Maintenance of drainage system

Table F4. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Lenawee silty clay loam, depressional	Severe: Wetness, frost action, floods	Fair: Raise grade of building site, reinforced slab, type II slab on grade, improve drainage control	Moderate: Flooding restricting accessibility and yard use, maintenance of drainage system
Marlette loam, 2 to 6 percent slopes	Moderate: Frost action	Good: Type II slab on grade	Slight:
Marlette loam, 6 to 12 percent slopes Marlette clay loam, 6 to 12 percent eroded	Moderate: Slope, frost action	Good: Cuts and fills reinforce slab, type II slab on grade	Slight: Erosion and drainage control
Marlette loam, 12 to 18 percent slopes	Severe: Slope	Fair: Cuts and fills reinforce slab, type II slab on grade	Moderate: Erosion and drainage control
Marlette loam, 18 to 25 percent slopes	Severe: Slope	Poor: Cuts and fills, reinforced slab, type II slab on grade	Severe: Erosion and drainage control

Table F4. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Matherton loam, 0 to 3 percent slopes	Severe: Wetness, frost action	Fair: Drainage of footing and slab, reinforce slab, type II slab on grade, improve drainage control	Moderate: Maintenance of drainage system
Metamora-Capac sandy loams, 0 to 4 percent slopes for Capac part see Capac series	Severe: Wetness, frost action	Fair: Drainage of footing and slab, reinforce slab, type II slab on grade, improve drainage control	Moderate: Maintenance of drainage system
Metea series Mapped only in complex with Spinks soils			
Metea part of Spinks-Metea loamy sands, 0 to 6 percent slopes	Moderate: Frost action	Excellent: Reinforce slab, type II slab on grade	Slight:

Table F4. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Metea part of Spinks-Metea loamy sands, 6 to 12 percent slopes	Moderate: Slope, frost action	Good: Cuts and fills, re-inforce slab, type II slab on grade	Slight: Erosion and drainage control
Oshtemo sandy loam, 0 to 6 percent slopes	Slight:	Excellent: Type I slab on grade	Slight:
Oshtemo sandy loam, 6 to 12 percent slopes	Moderate: Slope	Good: Cuts and fills, type I slab on grade	Slight: Erosion and drainage control
Owosso-Marlette sandy loams, 1 to 6 percent slopes For Marlette part see Marlette series.	Moderate: Frost action	Good: Type II slab on grade	Slight:
Owosso-Marlette sandy loams, 6 to 12 percent slopes For Marlette part see Marlette series.	Moderate: Frost action, slope	Good: Cuts and fills, reinforce slab type II slab on grade	Slight: Erosion and drainage control

Table F4. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Owosso-Marlette sandy loams, 12 to 18 percent slopes	Severe: Slope	Fair: Cuts and fills, reinforce slab,type II slab on grade	Moderate: Erosion and drainage control
Palms muck	Severe: Wetness, floods, low strength	Poor: Excavate peat and muck, raise grade of building site, reinforce slab, type II slab on grade, improve drainage control	Severe: Flooding restricting accessibility and yard use, maintenance of drainage system
Parkhill loam	Severe: Wetness, floods, frost action	Fair: Raise grade of building site, drainage of footing on slab, reinforce slab, type II slab on grade, improve drainage control	Moderate: Flooding restricting accessibility and yard use, maintenance of drainage system
Sebewa loam	Severe: Wetness, floods, frost action	Fair: Raise grade of building site, drainage of footing and slab, reinforce slab, type II slab on grade, improve drainage control	Moderate: Flooding restricting accessibility and yard use, maintenance of drainage system

Table F4. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Shoals-Sloan loams For Sloan part see Sloan series	Severe: Wetness, floods, frost action	Poor: Raise grade of building site, re-inforce slab, type II slab on grade, improve drainage control	Severe: Flooding restricting accessibility and yard use, maintenance of drainage system
Sloan series Mapped only in a complex with Shoals series	Severe: Wetness, floods, frost action	Poor: Raise grade of building site, re-inforce slab, type II slab on grade, improve drainage control	Severe: Flooding restricting accessibility and yard use, maintenance of drainage system
Spinks loamy sands, 0 to 6 percent slopes	Slight	Excellent: Type I slab on grade	Slight:
Spinks-Metea loamy sands, 0 to 6 percent slopes For Metea part see Metea series			
Spinks loamy sands, 6 to 12 percent slopes	Moderate: Slope	Good: Cuts and fills, type I slab on grade	Slight: Erosion and drainage control

Table F4. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Spinks-Metea loamy sands, 6 to 12 percent slopes For Metea part see Metea series			
Spinks part of Boyer-Spinks loamy sands, 12 to 18 percent slopes	Severe: Slope	Fair: Cuts and fills, type I slab on grade	Moderate: Erosion and drainage control
Tuscola fine sandy loam, 0 to 4 percent slopes	Severe: Frost action, low strength	Good: Type II slab on grade	Slight:
Wasepi sandy loam, 0 to 3 percent slopes	Severe: Frost action, wetness	Fair: Drainage of footing and slab, reinforce slab, type II slab on grade, improve drainage control	Moderate: Maintenance of drainage system
Wasepi sandy loam bedrock variant, 0 to 3 percent slopes	Severe: Frost action, wetness, depth to bedrock	Fair: Drainage of footing and slab, reinforce slab, type II slab on grade, improve drainage control	Slight: Maintenance of drainage system

Table F4. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Winneshiek silt loam, 0 to 3 percent slopes	Moderate: Frost action	Good: Reinforce slab, Type II slab on grade	Slight:

Table F5. Soil potential ratings, recommended designs to overcome soil limitations, and continuing limitation of soils for residential waterlines in Eaton County, Michigan

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Adrian muck	Severe: Wetness, unstable organic material, floods, corrosive	Poor: Excavate peat and muck, dewater trench, install cast iron water pipe, wrap pipe with polyethylene	Severe: Flooding restricing repair and causing health hazard
Bixby loam, 0 to 3 percent slopes	Moderate: Cutbanks cave	Excellent: Install cast iron water pipe with pipe trencher	Slight:
Borrow land Properties too variable to be interpreted, on-site inspection needed			
Boyer loamy sand, 0 to 6 percent slopes	Severe: Cutbanks cave	Excellent: Install cast iron water pipe with pipe trencher	Slight:
Boyer loamy sand, 6 to 12 percent slopes	Severe: Cutbanks cave, slope	Good: Install cast iron water pipe with pipe trencher, backfill carefully tamped	Slight: Erosion control for trench area

Table F5. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Boyer-Spinks loamy sands, 12 to 18 percent slopes For Spinks part see Spinks series	Severe: Slope, cutbanks cave	Poor: Install cast iron water pipe with pipe trencher, backfill carefully tamped thrust blocking and anchoring	Moderate: Erosion control for trench area, backfill slipping downfill
Brady-Bronson sand loams, 0 to 3 percent slopes For Bronson part see Bronson series	Severe: Wetness, cutbanks cave	Good: Dewater trench, install cast iron water pipe with pipe trencher.	Slight:
Bronson series Mapped only in a complex with Brady soils	Severe: Wetness, cutbanks cave	Good: Dewater trench, install cast iron water pipe with pipe trencher.	Slight:
Capac loam, 0 to 3 percent slopes	Severe: Wetness, corrosive	Fair: Dewater trench, install cast iron water pipe with pipe trencher, wrap pipe with polyethylene	Slight:

Table F5. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Capac-Marlette loams, 1 to 3 percent slopes For Marlette part see Marlette series	Severe: Wetness, corrosive	Fair: Dewater trench, install cast iron water pipe with pipe trencher, wrap pipe with polyethylene	Slight:
Cohoctah fine sandy loam, frequently flooded	Severe: Wetness, floods, corrosive	Poor: Dewater trench, install cast iron water pipe with pipe trencher, wrap pipe with polyethylene	Severe: Flooding restricting repair and causing health hazard
Colwood loam Colwood loam, depressional	Severe: Wetness, floods, cutbanks cave, corrosive	Fair: Dewater trench, install cast iron water pipe with pipe trencher, wrap pipe with polyethylene	Moderate: Flooding restricting repair and causing health hazard

Table F5. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Edwards muck	Severe: Wetness, instable organic material, floods, corrosive	Poor: Excavate peat and muck, dewater trench, install cast iron water pipe, wrap pipe with polyethylene	Severe: Flooding restricting repair and causing health hazard
Gilford sandy loam	Severe: Wetness, cutbanks cave, corrosive	Fair: Dewater trench, install cast iron water pipe with pipe trencher, wrap pipe with polyethylene	Moderate: Flooding restricting repair and causing health hazard
Hillsdale sandy loam, 2 to 6 percent slopes	Slight:	Excellent: Install cast iron water pipe with pipe trencher	Slight:
Hillsdale sandy loam, 6 to 12 percent slopes	Moderate: Slope	Good: Install cast iron water pipe with pipe trencher, backfill carefully tamped	Slight: Erosion control for trench area

Table F5. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Houghton muck	Severe: Wetness, unstable organic material, floods, corrosive	Poor: Excavate peat and muck, dewater trench, install cast iron water pipe with pipe trencher, wrap pipe with polyethylene	Severe: Flooding restricting repair and causing health hazard
Kibbie fine sandy loam, 0 to 3 percent slopes	Severe: Wetness, cutbanks cave, corrosive	Fair: Dewater trench, install cast iron water pipe with pipe trencher, wrap pipe with polyethylene	Slight:
Lenawee silty clay loam, depressional	Severe: Wetness, floods, corrosive	Fair: Dewater trench, install cast iron water pipe with pipe trencher, wrap pipe with polyethylene	Moderate: Flooding restricting repair and causing health hazard
Marlette loam, 2 to 6 percent slopes	Moderate: Cutbanks cave	Excellent: Install cast iron water pipe with pipe trencher	Slight:

Table 55. Continued

Table F5. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Marlette loam, 6 to 12 percent slopes Marlette clay loam, 6 to 12 percent slopes, severely eroded	Moderate: Cutbacks cave, slope	Good: Install cast iron water pipe with pipe trencher, backfill carefully tamped	Slight: Erosion control for trench area
Marlette loam, 12 to 18 percent slopes	Severe: Slope	Poor: Install cast iron water pipe with pipe trencher, backfill carefully tamped, thrust blocking and anchoring	Moderate: Erosion control for trench area, backfill slipping downhill
Marlette loam, 18 to 25 percent slopes	Severe: Slope	Poor: Install cast iron water pipe with pipe trencher, backfill carefully temped, thrust blocking and anchoring	Severe: Erosion control for trench area, backfill slipping downhill
Matherton loam, 0 to 3 percent slopes	Severe: Wetness, cutbanks cave, corrosive	Fair: Dewater trench, install case iron water pipe with pipe trencher, wrap pipe with polyethylene	Slight:

Table F5. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Metamora-Capac sandy loams, 0 to 4 percent slopes For Capac part see Capac series	Severe: Wetness, corrosive	Fair: Dewater trench, install cast iron water pipe with pipe trencher, wrap pipe with polyethylene	Slight:
Metea series Mapped only in complex with Spinks soils			
Metea part of Spinks-Metea loamy sands, 0 to 6 percent slopes	Slight:	Excellent: Install cast iron water pipe with pipe trencher	Slight:
Metea part of Spinks-Metea loamy sands, 6 to 12 percent slopes	Moderate: Slope	Good: Install cast iron water pipe with pipe trencher, backfill carefully tamped	Slight: Erosion control for trench area
Oshtemo sandy loam, 0 to 6 percent slopes	Severe: Cutbanks cave	Excellent: Install cast iron water pipe with pipe trencher	Slight:

Table F5. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Oshtemo sandy loam, 6 to 12 percent slopes	Severe: Cutbanks cave, slope	Good: Install cast iron water pipe with pipe trencher, backfill carefully tamped	Slight: Erosion control for trench area
Owosso-Marlette sandy loams, 1 to 6 percent slopes For Marlette part see Marlette series	Slight:	Excellent: Install cast iron water pipe with pipe trencher	Slight:
Owosso-Marlette sandy loams, 6 to 12 percent slopes For Marlette part see Marlette series	Moderate: Slope	Good: Install cast iron water pipe with pipe trencher, backfill carefully tamped	Slight:
Owosso-Marlette sandy loams, 12 to 18 percent slopes For Marlette part see Marlette series	Severe: Slope	Poor: Install cast iron water pipe with pipe trencher, backfill carefully tamped, thrust blocking and anchoring	Moderate: Erosion control for trench area, backfill slipping downhill

Table F5. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Palms muck	Severe: Wetness, unstable organic matter, floods, corrosive	Poor: Excavate peat and muck, dewater trench install cast iron water pipe with pipe trencher, wrap pipe with polyethylene	Severe: Flooding restricting repair and causing health hazard
Parkhill loam	Severe: Wetness, floods, corrosive	Fair: Dewater trench, install cast iron water pipe with pipe trencher, wrap pipe with polyethylene	Moderate: Flooding restricting repair and causing health hazard
Sebewa loam	Severe: Wetness, floods, corrosive	Fair: Dewater trench, install cast iron water pipe with pipe trencher, wrap pipe with polyethylene	Moderate: Flooding restricting repair and causing health hazard

Table F5. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Shoals-Sloan loams For Sloan part see Sloan series	Severe: Wetness, floods, corrosive	Poor: Dewater trench, install cast iron water pipe with pipe trencher, wrap pipe with polyethylene	Severe: Flooding restricting repair and causing health hazard
Sloan series Mapped only in a complex with Shoals soils	Severe: Wetness, floods, corrosive	Poor: Dewater trench, install cast iron water pipe with pipe trencher, wrap pipe with polyethylene	Severe: Flooding restricting repair and causing health hazard
Spinks loamy sand, 0 to 6 percent slopes	Severe: Cutbanks cave	Excellent: Install cast iron water pipe with pipe trencher	Slight:
Spinks-Metea loamy sands, 0 to 6 percent slopes For Metea part see Metea series			

Table F5. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Spinks loamy sand, 6 to 12 percent slopes	Severe: Slope, cutbanks cave	Good: Install cast iron water pipe with pipe trencher, backfill carefully tamped	Slight: Erosion control for trench area
Spinks-Metea loamy sands, 6 to 12 percent slopes For Metea part see Metea series			
Spinks part of Boyer-Spinks loamy sands, 12 to 18 percent slopes	Severe: Slope, cutbanks cave	Poor: Install cast iron water pipe with pipe trencher, backfill carefully tamped thrust blocking and anchoring	Moderate: Erosion control for trench area, backfill slipping downfill
Tuscola fine sandy loam, 0 to 4 percent slopes	Severe: Wetness, cutbanks cave	Good: Dewater trench, install cast iron water pipe with pipe trencher	Slight:

Table F5. - Continued

Soil Mapping Unit	Limitations and Restrictions	Soil Potential and Corrective Measures	Continuing Limitations
Wasepi sandy loam, 0 to 3 percent slopes	Severe: Wetness, cutbanks cave	Good: Dewater trench, install cast iron water pipe with pipe trencher	Slight:
Wasepi sandy loam, bedrock variant, 0 to 3 percent slopes	Severe: Depth to bedrock, wetness	Poor: Excavate rock, install cast iron water pipe with water trencher	Slight:
Winneshiek silt loam, 0 to 3 percent slopes	Moderate: Wetness	Good: Dewater trench, install cast iron water pipe with pipe trencher	Slight:

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